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A REVIEW OF THE CURRENT TECHNIQUES OF PROTECTING AND COOLING ROCKET MOTOR WALLS

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SUMMARY

The current techniques of protecting and cooling liquid propellant rocket-motor walls are described. The underlying physical principles are explained for each case in an elementary way, and, with the aid of diagrams, some of the advantages and shortcomings of each technique are pointed out.

Introduction

The development of the liquid propellant rocket motor to a reliable propulsion unit presented the research and development engineer with a host of new problems and it is probably right to say that one of the most difficult ones was to find reliable techniques to protect the walls of the rocket motor from the attack of the hot combustion gases. The combination of high temperatures, high pressures, and combustion gas velocities up to three times the velocity of sound results in exceedingly high rates of heat transfer to the surrounding walls. Heat flow densities, i.e. heat transmitted per unit of surface in unit of time, in the order of 3 B.T.U./sq. in. sec. have been observed in the combustion chamber and peak values of up to 12 B.T.U./sq. in. sec. in the throat of the expansion nozzle. These figures become more impressive when converted to the more familiar mechanical units, in which the equivalent of thermal flux amounts to 5 h.p./sq. in. for the combustion chamber and 20 h.p./sq. in. for the throat of the nozzle. Values of such magnitude had never been observed before in engineering practice. For comparison the heat flow density in a modern steam generator is of the order of 0·03 B.T.U./sq. in. sec. and even peak values in internal combustion engines are only approximately 0·07 B.T.U./sq. in. sec.

During the early stages of rocket engineering neither our experimental nor our theoretical knowledge were sufficiently advanced to predict heat transfer with the accuracy required for the development and design of cooling methods. Consequently many futile experiments were carried out which usually ended with a beautiful new rocket motor being turned into a lump of molten metal

within a few seconds. Research and development were further complicated by the existence of various unexpected phenomena. Nobody would have predicted for instance, that with the onset of oscillating combustion, the so-called "chugging" of the motor, the heat transfer rate would rise to as much as three times of its normal value. It need not be pointed out what was left of an otherwise well designed and normally well functioning rocket unit after such a test.

In the following sections a brief account will be given on the current techniques which have been developed and used to protect the motor walls against the effect of the hot combustion products, and indicating the principles involved, their particular advantages and limitations.

The Thermal Capacity Technique

The earliest technique, at present applied to low energy propellants (solid propellants) and occasionally short-duration liquid propellant rocket motors, is the thermal capacity technique.

The entire motor, or certain parts, of it consist of thick-walled bodies of revolution made of various metals.

The heat transmitted from the hot combustion gases is taken up by the surrounding walls, causing their temperature to rise with time until a safe upper temperature limit is reached. That limit is, for high energy liquid propellants with combustion temperatures, between 2,500° K. and 3,500° K., and conventional metals, the melting point of the wall material. Continuing the heating beyond that critical temperature would lead to extensive melting on the inner surfaces and eventually to the destruction of such a unit. A steady state operation of a motor of this kind is therefore impossible and the obvious question is, how long could it be operated safely and which materials give the longest time of operation for a given propellant combination.

For a better understanding of the problem the state immediately after the start of the motor during successive small time intervals will be considered. At the moment of ignition, hot combustion products sweep over the surfaces of the motor walls and transmit heat to the metal layers in immediate contact with the gas stream. The temperature of the surface layers will increase, the temperature increase being dependent on the specific heat of the material used and its density. The higher the density and the specific heat—or in other words, the higher the thermal capacity (B.T.U./ft.^{3} °F.), the smaller the temperature rise. During the following time intervals more heat is being transferred to the surface causing the temperature to rise there steadily, but owing to the temperature gradient set up now in the wall itself, heat will also flow away from the hot layers and spread into the depth of the wall. This process is controlled by the thermal conductivity of the wall material. As the rate of heat transfer from the gas stream to the wall is very high, the heat absorbed on the surface cannot be conducted away fast enough and the surface temperature will reach the melting point, while at a moderate distance from the surface the material has remained relatively cool. The thermal capacity of the wall is thus only partially exploited.

With the aid of some simplifying assumptions (flat slab, constant thermal

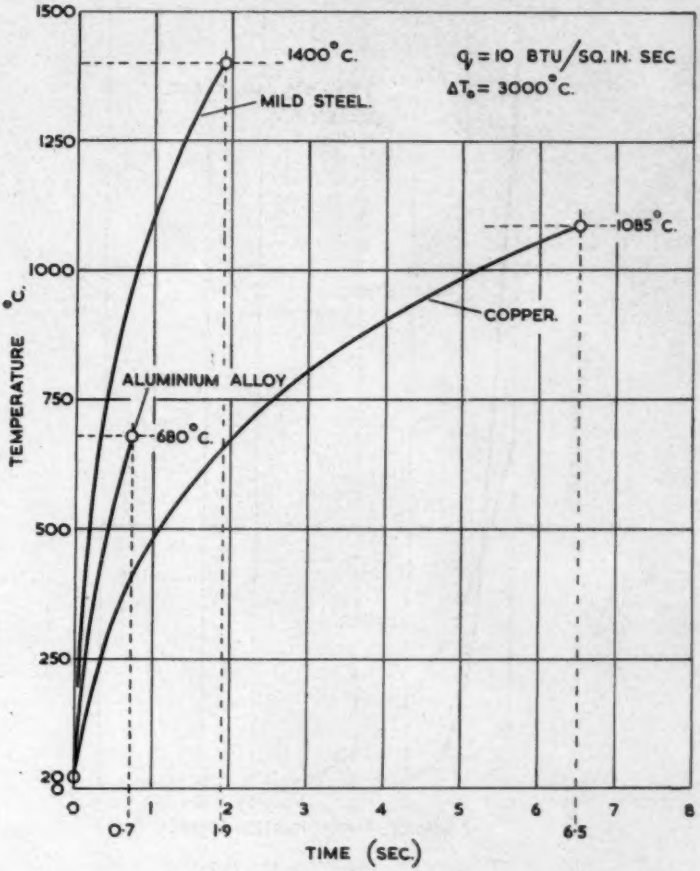


FIG. 1. Safe times of operation for three conventional materials exposed to conditions representative of the throat area in the expansion nozzle of a liquid propellant rocket motor.

properties) the temperature rise with time has been determined for three typical materials, viz., copper, mild steel and an aluminium alloy of the Dural type and is shown in Fig. 1.

The conditions of heat exchange leading to this diagram are representative of the throat area in a liquid propellant rocket motor, with heat flow densities at about 10 B.T.U./sq. in. sec. and an initial temperature difference between gas and wall of 3,000° C. The diagram represents the rise of temperature with time on the surface of the metal wall in contact with the combustion gases.

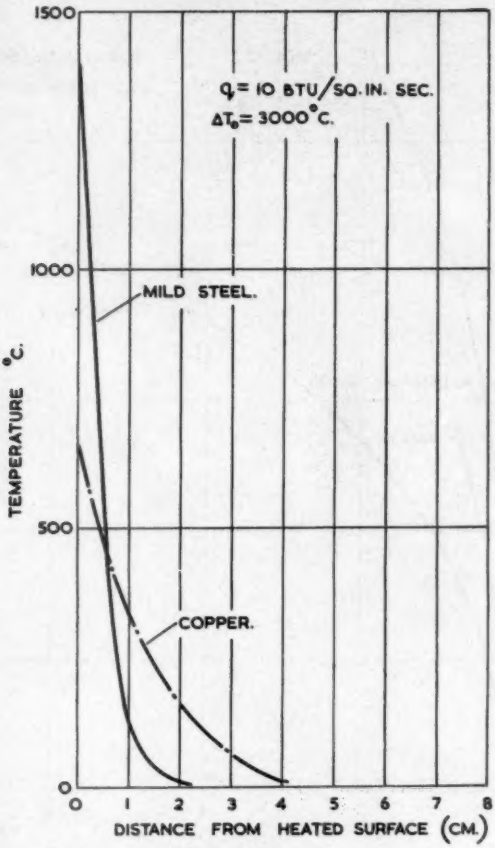


FIG. 2. Temperature distribution in a copper and a mild steel slab after 2 secs.

The relation is only extended to the corresponding melting points which are regarded as the critical temperature limits. Of the three materials, copper is distinctly superior to the other two. Use of this fact has been made for experimental type motors where solid copper expansion nozzles have been used with some success.

It is also quite interesting to compare the temperature distribution in the wall for different materials after a certain period of time.

Fig. 2 shows the temperature distribution in solid walls made of copper and of mild steel, after having been exposed for 2 seconds to a heat flow density of 10 B.T.U./sq. in sec. at 3,000° C. initial temperature difference. This

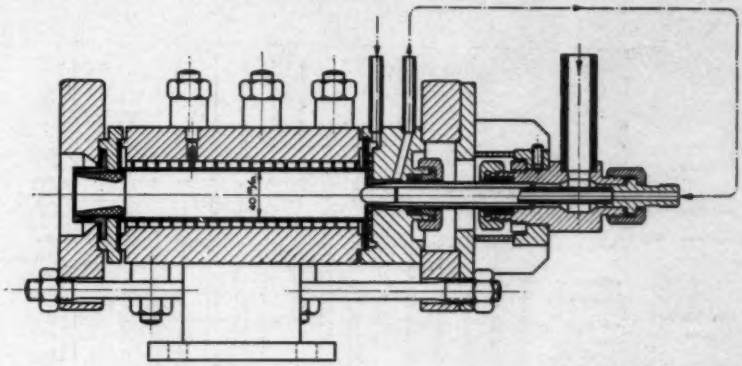


FIG. 3. Experimental rocket motor with refractory nozzle.

comparison is of particular interest, as copper and mild steel have approximately the same thermal capacity but considerably different thermal conductivities. It can be seen that in the case of the poorer thermal conductor, viz., mild steel, the heat absorbed on the gas-wall interface cannot be conducted away at the same rate as for copper. Consequently the temperature at the surface rises sharply and has reached the melting point after only 2 seconds while at a distance of only 2 cm. from the surface, the temperature is still at the initial value.

Apart from occasional experimental applications, the thermal capacity technique has gained no practical importance. Weight considerations would prohibit the use of heavy solid metal bodies, even if the short duration were acceptable.

Refractory Materials

It can easily be understood that materials having a lesser thermal conductivity than mild steel will show an even sharper temperature rise with time and the depth of penetration of the heat flow will be confined to a thin layer on the surface. Should the material, in addition, possess a melting point higher than the combustion gas temperature, the wall could safely be heated to that level. Bearing in mind, that convective heat exchange is proportional to the temperature difference between the heating gas and the heat absorbing wall, heat transmission to the wall will diminish with increasing wall temperature and tend towards zero when gas and wall temperature are nearly equal.

These consideration lead to another technique, which has been used fairly extensively, viz., the use of high refractory materials.

In view of the poor mechanical properties of refractory materials, particularly at high temperatures, motors designed on this protection technique consist of a refractory liner, surrounded by a metal casing to take the mechanical stress. Fig. 3 shows an experimental type rocket motor, giving about 30 lb. thrust, equipped with a ceramic expansion nozzle.

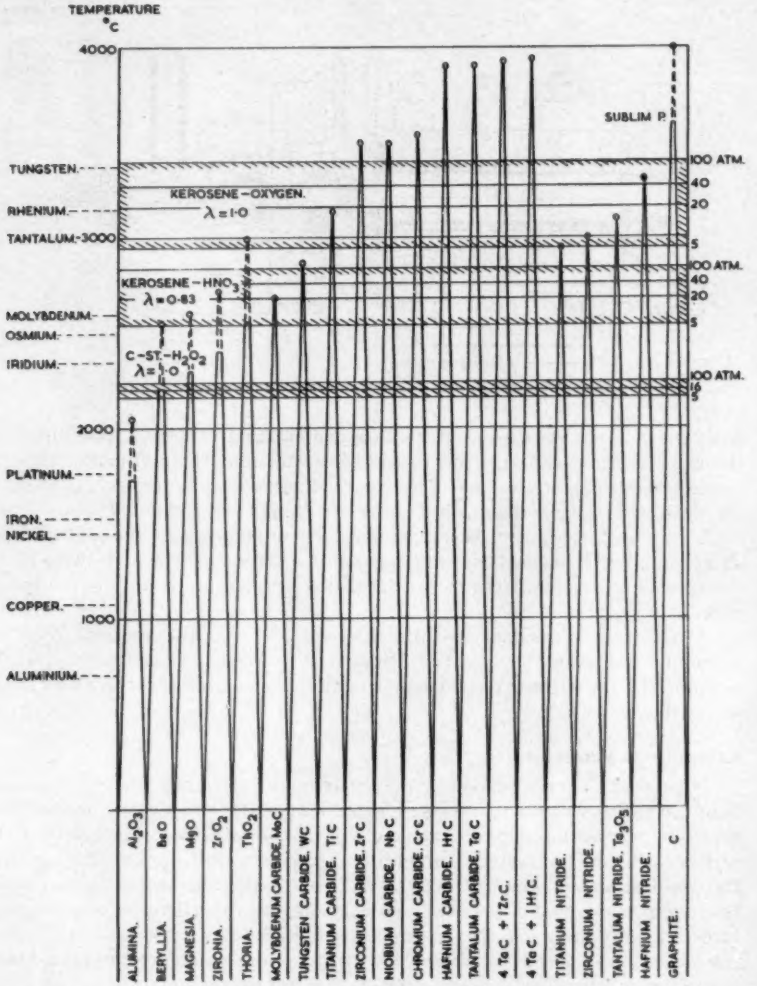


FIG. 4. Softening range and melting point of high refractory materials.

The use of refractory materials promises longer operating times than can be obtained with the thermal capacity technique. There is quite a number of materials that have very high melting points. However, a high melting point is not the sole criterion for its suitability as a constructional material. As a rule, the application of refractory materials is limited by two factors, viz., their

sensitiveness to chemical attack by the hot combustion gases and by an effect, called "Thermal Shock Sensitivity." Sudden changes in temperature lead to cracks in refractory bodies. This effect depends on the physical properties, such as thermal expansion, thermal conductivity and thermal diffusivity, as well as the mechanical strength of the material.

A survey on some high melting materials is presented in Fig. 4 showing their melting points, and where available, their softening points—in comparison with the combustion temperatures of the three best known liquid propellant combinations, oxygen-kerosene, nitric acid kerosene, and hydrogen peroxide-hydrazin-hydrate. It will be noted that some of the materials listed have melting points well within the region of the combustion temperatures developed in rocket motors.

However, only few of these materials have been tested under actual rocket motor conditions. Graphite, particularly when coated, gave relatively good results. Tungsten carbide and silicon carbide were used for expansion nozzles and were satisfactory up to temperatures not very much below their melting point.

Hardly any practical experience is available for the majority of the high melting carbides and nitrides, although, judging by their melting point alone, they seem to withstand the highest temperatures in conventional liquid propellant motors.

Concluding, it can be said that by using the right type of refractory materials the running time of an uncoooled motor can be considerably increased. For certain propellant combinations the operating time can be extended to about 60 seconds.

External Cooling

The most widely used method is to circulate a cooling fluid through channels of narrow cross section which are arranged on the outer surface of the walls in contact with the hot combustion gases.

A typical representative of this type of motor is shown in Fig. 5. Although it is only a small experimental motor it contains all the essential features of an externally cooled motor. The combustion chamber consists of an inner copper liner 1, with helical grooves on its outer surface to ensure the forced flow of the coolant. At the expansion nozzle end this liner is screwed into a brass casing 2, while a stuffing box 3, prevents leakage of the coolant at the opposite end. This arrangement permits free expansion of the liner 1, in the casing 2, which during the operation of the motor is at a considerably lower temperature.

The expansion nozzle again consists of a copper body surrounded by a bronze ring. Grooves are cut in this ring to guide the coolant with the required velocity.

External liquid cooling allows the motor to operate continuously at steady state conditions, as the heat transmitted by the combustion gases to and conducted through the wall is continuously removed by the coolant. For static firings, water is usually preferred as a coolant on account of its excellent thermal properties, availability and ease of handling. For an actual operational motor, however, weight considerations may not allow another liquid to be used

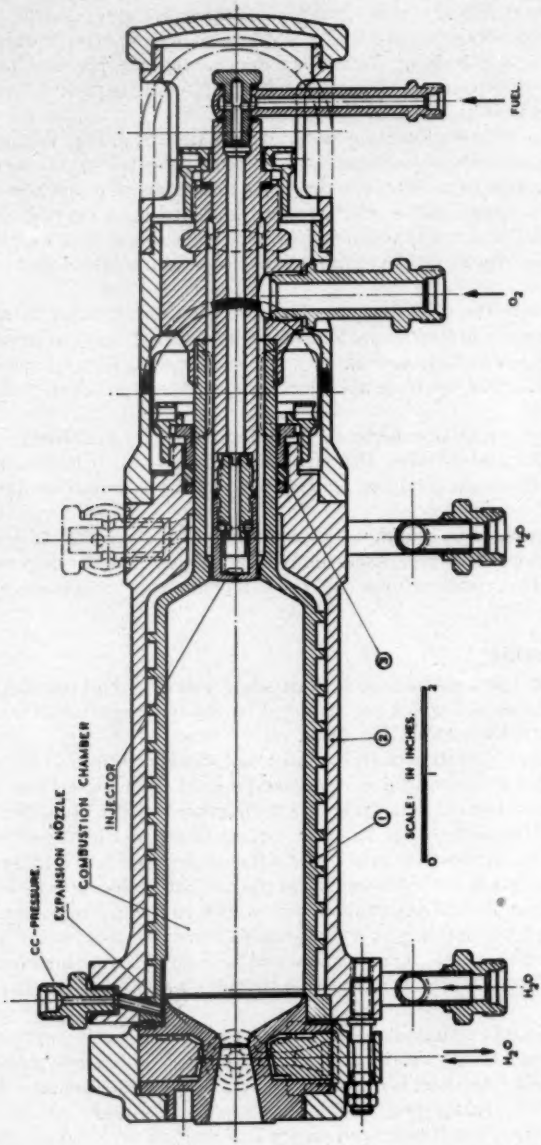


FIG. 5. Combustion chamber 1/T30/CP20/60X.
(Crown copyright)

and one, or both of the propellants may have to be used as cooling fluids. This fact, somewhat restricts the application of regenerative external cooling to larger motors.

Owing to the extremely high heat flow densities encountered in rocket motors, heat conduction, even through a relatively thin and good conducting metal wall, results in considerable temperature gradients. The thermal resistance of the wall, usually a negligible factor in ordinary heat exchanger evaluations, becomes a significant factor. Due regard has to be given to thermal conductivity, and thus it may not be possible to use any or every material for wall construction which appears to offer other advantages, say ease of manufacture. To illustrate this point, the temperature gradient in a flat wall of *2·5 mm.* (0·1 in.) *thickness* has been evaluated as a function of heat-flow density and is shown in Fig. 6. The temperature on the cooled side of the wall was assumed to be 200° C. and constant for all heat-flow densities. The gas-surface wall temperature was evaluated for four typical materials, viz., mild steel, 18/8 Cr/Ni steel, copper and aluminium. In the heat flux range from 1 to 4 B.T.U./sq. in. sec., which is representative of the conditions in the combustion chamber of a liquid propellant rocket motor, all four materials seem to be suitable. For heat-flow densities that have been observed in the throat area of rocket expansion nozzle, i.e. heat fluxes from 6 to 10 B.T.U./sq. in. sec. and higher, only copper and aluminium, both of which are very good thermal conductors, appear to be safe materials of construction.

On the coolant side, these high heat fluxes can only be controlled by high coolant velocities and in consequence the pressure losses in the cooling passages due to friction and increased turbulence can be large. Considering a motor cooled by one of the propellants, it is essential that the static pressure of the propellant at the entry to the propellant injector is somewhat above the combustion pressure to ensure adequate atomization and distribution. A value of 60 lb./sq. in. is a good average figure. This pressure drop is added to the pressure losses already incurred for circulation of the propellant over the cooled surface area. They may be considerable, as they vary with the square of the coolant velocity. During the motor operation the jacket separating the coolant and the combustion gases is therefore exposed to an external pressure which is equal to the sum of the injection pressure drop and the frictional loss. Shortly after the start, before the combustion pressure has been fully built up, this external load on the jacket is considerably higher and may be as high as the entry pressure of the propellant into the cooling channel.

Bearing in mind the importance of reducing the thermal resistance of the motor wall, which in fact means reducing the thickness of the wall for a given material, one can realize the two contradictory demands imposed upon the designer.—Relatively strong and thick walls to withstand the external pressure of the coolant and thin walls to reduce their thermal resistance. While this problem is perhaps not so important for small motors, it may cause considerable headache in the design of a larger unit, as the maximum external pressure for a cylindrical tube (excess pressure over combustion pressure) is inversely proportional to the cube of the tube radius. To take a practical example: The inner liner of a combustion chamber may consist of a mild-steel tube, 4 in.

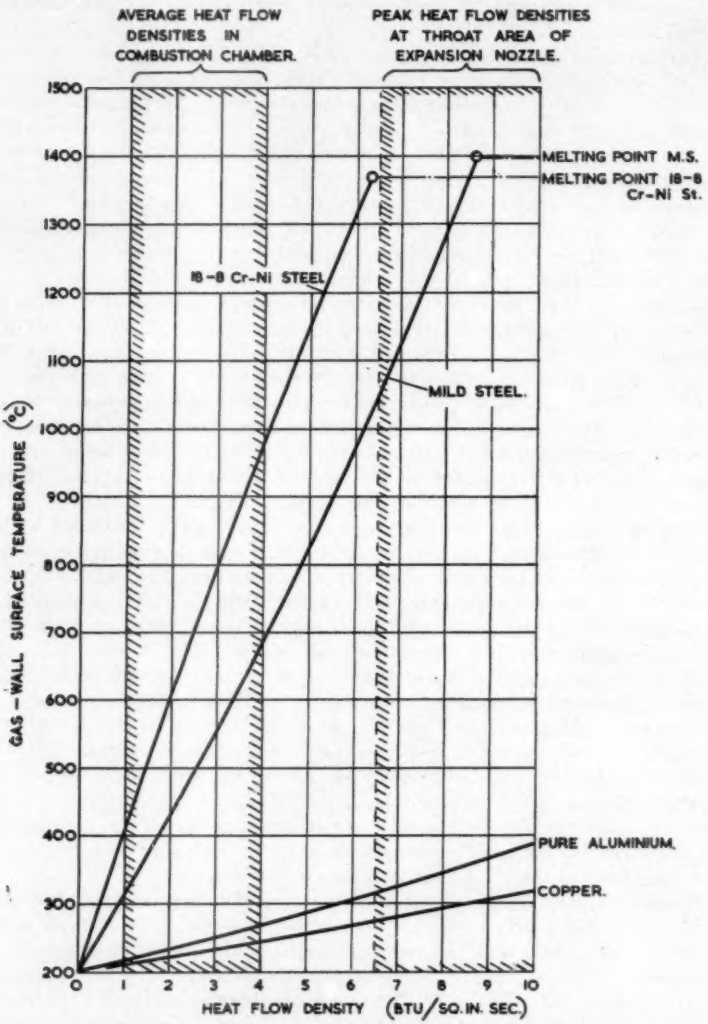


FIG. 6. Gas-surface wall temperature with heat flow density for four typical materials. Temperature of the cooled surface 200° C. wall thickness 2·5 m/m.

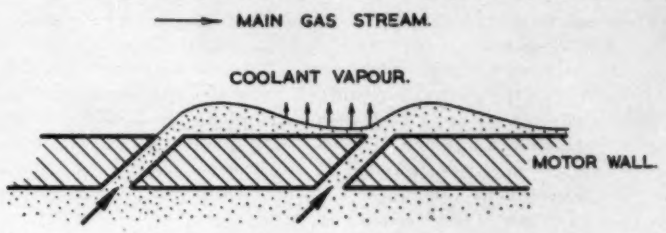


FIG. 7. Film cooling.

diameter, and have a wall thickness of $\frac{1}{8}$ in. The theoretical maximum external pressure which this tube would stand without buckling is about 1,600 lb./sq. in. If the design is scaled up to, say 10 times the thrust of the smaller unit, the geometrically similar chamber would have a diameter of about $\sqrt{10} \times 4$ in. = 12·7 in. diameter. For the same wall thickness the larger tube could stand an external pressure of only 45 lb./sq, in. It becomes at once obvious that the design of large combustion chambers from the structural point of view, is a considerably more difficult task, and special measures have to be taken to increase the buckling resistance of the large diameter liner.

Film Cooling

The choice of the constructional material for the inner liner of an externaliy cooled motor, however, is influenced not only by the thermal properties of the material, but very often, by practical considerations, such as availability, ease of fabrication, etc.

Mild steel, regarding its low price and favourable manufacturing properties is the most desirable material for large-scale production of rocket motors. However, its thermal properties are such that it cannot be used for transmission of very high heat flow densities as we have seen from the previous diagram, Fig. 6. There is, however, a technique of protecting the walls, which is practically independent of the conductivity of the metallic wall. I think the method was first suggested by Oberth, one of the early pioneers of rocket propulsion, and has been termed "*film cooling*," but is also known, as "*effusion cooling*," or "*transpiration cooling*."

While in external cooling heat transfer takes place through a bounding metal wall on to a coolant, the new method avoids some of the inherent shortcomings of this technique, as heat is absorbed by the coolant before it can reach the wall. This is achieved by injecting a fluid through a number of small holes arranged in the motor walls (*see* Fig. 7) in such a way, that, the fluid injected forms a continuous film on the surface of the wall, and thus forms a cool, protective layer which absorbs most of the heat transmitted by the combustion gases.

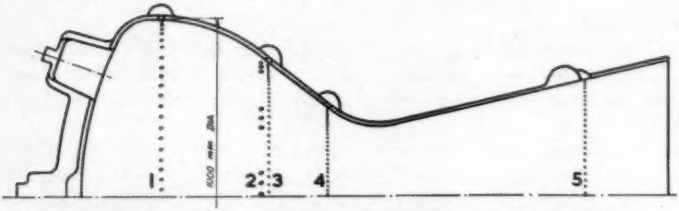
At a certain distance downstream from the point of injection the protective film becomes sufficiently heated and has become partially mixed with the main gas stream, so that it has to be replaced by a fresh one in an identical way.

Both gases and liquids can be used as coolants, but liquids are naturally more effective than gases because of their higher heat capacity, largely due to their high latent heat of evaporation. They are also more stable insofar as less turbulent mixing occurs with the main gas stream. But there is, another aspect in favour of liquid coolants. In large combustion chambers, or at high combustion pressures, a considerable amount of heat is transmitted by radiation. As most gases are nearly transparent to infra-red radiation, a gaseous film affords only protection against convective heat transfer, while heat radiated from the combustion gases penetrates to the motor walls.

However, many liquids, in particular water, absorb heat to a high extent, even in very thin layers. Heat radiated towards the wall would thus be largely absorbed in the coolant film. From all this it appears thus, that film cooling employing liquid coolants provides distinct advantages and when one has the choice, the liquid with the higher infra-red absorptivity should be selected.

The amount of coolant required naturally depends on the properties of the coolant (heat capacity) and on the amount of heat transferred from the gases. An average figure for the coolant requirements which should be regarded as a guide only, is 10 per cent. (by weight) of the main gas flow.

This method has been applied in practice for a number of operational motors, very often combined with external liquid cooling, to give additional protection to areas of high-flow densities.



ROW No.	1	2	3	4	5
NUMBER OF HOLES	88	4 ×36	150	90	140
DIAMETER OF HOLES mm	2	0.8	3	3	3
COOLANT QUANTITY kg/s	2.5	1.0	8.5	5.0	8.0

FIG. 8. Additional surface cooling by secondary injection. Combustion-chamber A4(V2).

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One of the early operational motors applying film cooling was the German V2 rocket (Fig. 8). The motor of the V2 was partially cooled externally by passing the fuel (alcohol-water mixture) over the surface in contact with the combustion gases. Additional protection was given to areas of high heat flow density by bleeding at various cross sections a certain amount of fuel through small holes on to the inner surface of the motor wall. In the schematic illustration the number and the position of these holes, and the total coolant flow rate for each section are given.

The correct positioning of these holes and the coolant flow rate through them is of great importance for the proper functioning of the system. Any change in conditions affecting the flow rate, say, e.g. by blockage of some of the holes, or by increased heat transfer, will lead to local overheating and possibly the loss of the unit.

Remedy was sought by increasing the number of cooling holes to ensure a more even distribution over the cooled surface and a reduction in the throughput of each hole. Manufacturing and practical considerations, however, restrict the reduction of hole size.

The ideal case of distributing a very large number of fine openings over the cooled surface can be achieved by using a porous material—either metallic or ceramic—for wall construction. The coolant is fed into a jacket surrounding the motor walls and is forced through the fine pores in the material on to the inner surface. Based on the physiological process the method is known as "*transpiration cooling.*" Although very simple in principle, great difficulties were encountered in producing porous bodies with an approximately uniform porosity.

Experiments which were conducted some time ago using gaseous coolants, established the principle. However, it was found more difficult to maintain a controlled liquid flow through a porous body. Arbitrary changes in the permeability both with time and location occurred frequently, and these have so far prevented the application of the method in rocket engineering.

In actual rocket motors designed for specific purposes a combination of the various methods is often employed, e.g. film cooling with external cooling (V2 motor); only the areas exposed to the severest thermal conditions are given additional protection by film cooling. In other cases ceramic liners are employed in externally cooled motors. Calculation of the cooling requirements for a new motor design still has to be followed by a fair amount of practical experimenting. This is partly due to some lack of knowledge on heat exchange processes, but to a greater extent to the effect of secondary influences which are difficult, if not impossible to assess numerically, such as the effect of injector design, motor configuration, etc.

Acknowledgment

Acknowledgment is made to the Chief Scientist, Ministry of Supply for permission to publish this paper and to Dr. C. H. Johnson for his encouragement and support.

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PROGRESS TOWARDS ASTRONAUTICS

By Kenneth W. Gatland

(*A paper read to The British Interplanetary Society in London on February 6, 1954*)

SUMMARY

Work in such fields as high-speed aerodynamics, aero-medical research, high-altitude sounding and guided-missiles is daily contributing to astronautical progress. Some of the most important current activities are concerned with the problems of supersonic flight, stability and control, automatic and remote guidance, aerodynamic heating, etc., and—in the realm of "inhabited" aircraft and missiles—the design of pressure suits, experiments with high-g. accelerations and, at the other extreme, research into the effects of zero-g. Continued experience in these fields may shortly lead to the first true space-flight projects, viz.: a minimum satellite vehicle, with the ultimate implication of human flight beyond the Earth's atmosphere.

Introduction

It seems scarcely possible that five years have elapsed since Mr. Cleaver's lecture to this Society on "Progress in Astronautics Since the War," which he gave in the spring of 1949. As a measure of our subsequent progress, it will be of interest to recall some of the developments surveyed in that talk.

It was part of Mr. Cleaver's purpose to show that real progress was being made in a variety of fields—starting with the vertical firings of the V2 rocket by the Americans at White Sands which, together with the small American-designed WAC Corporal rocket, had first opened up the exploration of the upper atmosphere in 1945–46.

February, 1949, saw the successful combination of the V2 and WAC Corporal, when the smaller rocket, launched from the nose of the V2 at a height of 20 miles, achieved a velocity of 5,000 m.p.h. and coasted nearly 250 miles into space. This remains our greatest physical achievement in the field of high-altitude research, although great strides have been made with single-stage rockets of the "Viking" type. But at the time of Mr. Cleaver's lecture in 1949, the first "Viking" of an original series of ten, developed under a Naval Research Laboratory contract by the Glenn Martin Company, had yet to be fired. However, the "Aerobee," a rocket similar in general layout to the WAC Corporal, but with superior performance, had proved a great success and was regularly achieving summit altitudes of 70 to 80 miles. This was a relatively cheap research vehicle, which has probably contributed more than any other to our knowledge of the upper atmosphere. The greatest altitude reached by V2 was 114 miles, but by 1949, only a few of these veteran rockets remained, and it was the turn of "Viking" to extend the region of investigation. But the V2 had done useful work and among the more dramatic results, Mr. Cleaver was able to show pictures of the Earth's surface from a height of 60 miles.

In the field of aviation, the lecturer referred to American high-speed research aircraft. The Bell X-1 research 'plane had achieved supersonic flight in October, 1947, reaching a speed which has since been quoted as 967 m.p.h.—achieved at an altitude of over 70,000 ft. It is now a museum-piece in the Smithsonian Institute. In 1949, the newer Douglas "Skyrocket", which originally used both turbo-jet and rocket propulsion, was undergoing early

trials. Meanwhile two years earlier in Britain, the lamentable decision had been taken by Sir Ben Lockspeiser and his advisors to scrap the half-completed Miles M-52 supersonic aircraft "because piloted flight at such speeds was considered too dangerous." In place of the full-scale aircraft, a series of pilotless models, patterned generally on the lines of the M-52, were produced which relayed basic information of performance to a ground receiving station. These models were a joint R.A.E./Vickers Armstrong venture and the best performance was a speed of about 900 m.p.h. obtained at an altitude of 30,000 ft., the models having been released at that height from a Mosquito aircraft. It is scarcely necessary to add that Britain has yet to achieve supersonic speeds in level flight with a piloted aircraft, whereas the American research effort, as we shall see later, has already yielded Mach 2.5 with development pressing on to Mach 3.0 and the problems of the so-called "heat-barrier."

In the sphere of guided-missiles, Mr. Cleaver was able to mention the North American NATIV, the Convair 774 and an early example of the Boeing GAPA project, which has since been revealed as a development programme embracing several types of rocket and ram-jet missiles.

But perhaps what appeared most significant of all to the cause of astronautics was the announcement in December, 1948, from no less an authority than the United States Secretary of Defence, that there was, in existence in America, an "Earth Satellite Vehicle Programme." This, Mr. Cleaver said, probably amounted to an effort, in the first place, to achieve a relatively small unmanned orbital rocket, capable of telemetering instrument readings back to Earth.

Finally, in the theoretical sphere, there were the newly published papers by Alverez, Malina, and others, discusssing the possibility of rockets for achieving orbital or escape missions. Some of these papers had mentioned the long-term possibility of building an atomic-rocket, in which nuclear energy would be used to heat up a secondary working fluid such as hydrogen, to form a propulsive jet. Mr. Cleaver felt that we had to look to such a device to realize the full potential of interplanetary flight. But, as an initial project, Malina and Summerfield in one of their classic papers had shown the practicability of achieving escape-velocity with pilotless step-rockets using readily available propellants. As an example, an acid-aniline rocket having a gross mass of 823,000 lb. and consisting of five steps, could project away from the Earth a payload of 10 lb. In the case of an oxygen/hydrogen "escape" rocket with this same 10 lb. payload, it was found that with five steps, the take-off mass would be reduced to only 8,320 lb. This reduction in mass as compared with the acid-aniline five-step rocket emphasized the importance of developing practical high-performance rocket systems, but it was nevertheless interesting to note that, with careful design, experiments of a unique and fundamental nature could be carried out in interplanetary space with present-day conventional propellants.

These, then, were the achievements and opinions recorded in 1949. How much farther have we progressed by 1954?

Despite the fact that definite space-flight projects have yet to materialize, a great deal of useful preliminary work has been accomplished. If rocket-powered aircraft appear to have little to do with interplanetary travel, for example, it

NACA Research Model.

This is one of a series of research models used to study the effect of the fuselage shape on drag. Various fineness ratios (ratio of length to diameter) have been studied as well as the shape of a particular body. The data obtained are of a fundamental nature, useful in the design of both supersonic aircraft and guided missiles. The models of this series attain a speed of about 1,300 miles per hour. The booster rocket (beneath) fires first, carrying the model up to the speed of sound. Then the model's internal rocket is ignited, and the model streaks away from the booster. The drag, or amount of air resistance, is calculated by measuring the rate of deceleration of the model after its internal rocket burns out, taking into consideration the weight of the model.

should be remembered that they have fostered the design of safe, reliable, rocket motors to the stage of permitting their use in manned vehicles. Indeed, such aircraft are particularly relevant to space-flight as they will provide experience in the type of winged craft that will be required to operate between the Earth's surface and the satellite orbit which, upon returning from the orbit will enter the atmosphere as supersonic gliders. Finally, in permitting human flight at altitudes near the fringe of the atmosphere, these aircraft are affording their pilots some experience of "free-fall" conditions.

Before we come to discuss these specific research aircraft, it will be of interest to consider some of the aerodynamic research techniques which the Americans have developed since the war. In 1945, despite the fact that a great deal was known about supersonic flight from the studies of ballistics, there existed at that time an almost complete gap in all the plotted curves of Mach number against drag coefficient in the transonic region. This gap could not be filled by tunnel experiments owing to unavoidable choking as sonic speed was reached.

Aerodynamic research

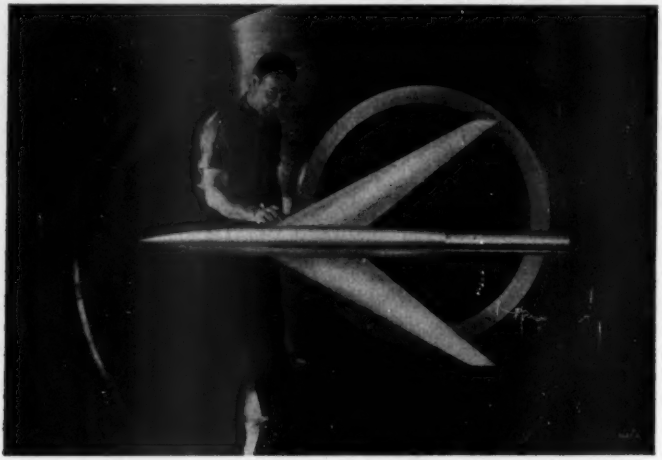
To meet this problem the National Advisory Committee for Aeronautics has, from 1945, conducted investigations into the nature of flight at transonic and supersonic speeds with rocket-propelled, free-flying, research models.[1]

The NACA facilities, based on the appropriately-named "Wallops Island," on the Virginia coast, do not constitute a missile test range like those at White Sands, New Mexico, or Banana River, Florida. It is an aerodynamics range, not a proving ground for missiles, and the rocket motor itself is not under test. The rocket unit merely provides the means of launching the models at high velocities.

The instrumented free-flight models came into extensive use as aerodynamic research tools towards the end of the last war as a result of the urgent need to obtain flight data at velocities approaching the speed of sound. The earliest tests utilized gravity for propulsion in the "free-fall" method, the models being dropped from aircraft flying high above the test area; both this and the rocket methods were producing useful data by the end of 1945.

Within the next few years free-flight techniques were devised which made it possible to attack nearly all the major high-speed problems in aerodynamics. Improvements in rocket motors, telemetering, model design, and the test methods themselves broadened the speed range through which tests could be made and also greatly increased the amount of information obtained from a given test. The primary development has been in the ground-launched rocket method, due to its greater flexibility, and solid-propellants are used almost without exception.

The techniques for obtaining continuous data from models operating at speeds far into the supersonic range involves the use of radar and radio combined with a suitable model and force-measuring instruments. The rocket propels the test-vehicle to the desired supersonic speed; radar is used to determine the location of the model in space and its velocity at any time during the flight. A special type of radio system, known as telemetering, is used to obtain a record of the various aerodynamic reactions of the model as measured by its instruments, which are transmitted directly to ground receiving stations.



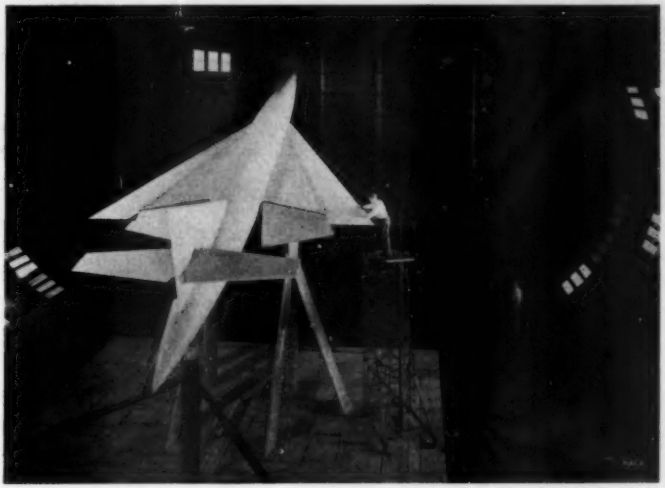
NACA Research Model.

Much study of swept-back wings for flight faster than sound has been accomplished in the laboratories of the NACA since 1944, when R. T. Jones of NACA first presented data to show that high degrees of sweep would tend to alleviate the adverse effects of shock waves encountered in the transonic speed range. This photograph illustrates one phase of such work. Taken in the 6 ft. by 6 ft. supersonic wind tunnel at Ames Aeronautical Laboratory, it shows a member of the tunnel staff adjusting a steel model with highly swept wings in the test chamber. The photograph was taken through one of the tunnel's optical-glass windows, through which high-speed airflow characteristics are studied while the tunnel is in operation.

The rocket models rapidly attain high speeds, passing through the transonic range and into the supersonic within a few seconds. The data sought by NACA are obtained during the entire flight, and especially when the vehicle is flying at transonic and supersonic speeds. Some useful information is picked up while the model is accelerating above 600 m.p.h., and considerably more when it is decelerating through the transonic range after propulsion has ceased.

After attaining a maximum speed in the region of 1,600 m.p.h., the research model, having expended its propellant, coasts freely through the air. Usually, a model has been assisted in take-off by a booster rocket; the test model separates just as the power of the booster is expended, a delayed fuse igniting the rocket charge embedded in the body. Sometimes, however, the model itself does not carry any rocket charge, and when the booster is expended, drag causes this unit to jettison, and the research model glides freely through the air. On the other hand, some of the larger rocket-propelled models take off under their own power without a booster. In certain tests a tiny research model is mounted on a balance projecting from the nose of the larger rocket which contains the instruments and propulsion charge.

The models rise to great heights and travel 5 to 10 miles before plunging into the sea several miles offshore. Many attain altitudes of 15,000 to 30,000 ft.;



NACA Research Model.

To study the possible beneficial effects of the addition of a conventional horizontal tail on the landing and takeoff characteristics of triangular-wing aircraft designed for supersonic flight, research engineers of the NACA's Ames Aeronautical Laboratory in California recently designed this 50-ft. 2½-ton experimental model and tested it extensively in the Laboratory's giant 40 ft. by 80 ft. wind tunnel. This photograph shows the model, complete with triangular-shaped fin and horizontal control surfaces, mounted in the test section. In the background can be seen turning vanes which pass the air smoothly around the wind tunnel's corners.

some have climbed as high as 100,000 ft. Top speeds range from 15 to 40 miles per minute, and most of the models attain a speed of 20 miles per minute (1,200 m.p.h.). Usually the entire flight is completed in less than two minutes—sometimes in only 30 to 40 seconds. During the first half or third of that period all the data required from a given model are obtained by an array of electronic devices, radio apparatus, and automatic recorders. Pressure-measuring devices, a radio-telemeter transmitter, and other miniature instruments are carried aloft in the model. Radio-receiving sets, recording apparatus, and a control panel for firing the rockets are housed in a concrete building at the launching site.

Most of the records are made photographically on fast-moving filmstrip, in such a manner that all the results of the test are recorded graphically on the same film and can be compared in relation to time and distance. Data obtained at any point of the flight can thus be clearly seen in relation to all other test conditions; even the distance the rocket has travelled from the launching site can be calculated within a few feet at any point on the film.

A model can be put through a series of programmed manœuvres simulating a wide range of flight conditions. It can be made to roll, climb, dive and turn by controls pre-set to work in sequence prior to take-off. The recorded reactions

of the model to these manœuvres are used to determine the manœuvrability, stability and control characteristics of the vehicle the scale model represents. Measurements of lift and drag are also obtained.

Although it is soon out of sight of visual observers, the model is tracked by radar and the information desired is radioed from the model by means of one to ten telemetering channels. The telemetering unit, powered by tiny batteries, is switched on just before the model is fired. Motion pictures are taken of all launchings, but undoubtedly the most valuable technical information is that radioed back to earth from the model itself.

The telemeter transmits readings given by numerous pressure pick-ups and other instruments. It transmits a continuous record of acceleration, position of the controls, forces acting on the controls, aerodynamic forces acting on the model (such as lift and drag), pressures acting on the surface of the model, attitude of the model in respect to airflow, and sometimes the surface temperature.

Two types of radar units are used, a Doppler velocity radar and a flight path radar. Radar tracking provides comparative data that can be matched with the data telemetered so that in the brief span of the flight all the information needed for research purposes is recorded automatically on drums of graph paper or on photographic film. All the test data needed from one model for a certain phase of research can therefore be obtained in a few vital seconds and seldom is it found necessary to launch more than one model of a specific design.

Usually the model does not resemble any specific project, but occasionally it takes the form of a dynamic scale model of a supersonic aircraft or missile which is still in the design stage. For example, data obtained at Wallops Island has proved extremely valuable in designing high-speed research aircraft such as the Douglas "Skyrocket," the Bell X-2 and the Douglas X-3.

Man into Space

The "Skyrocket" was designed and built for the U.S. Navy by the Douglas Aircraft Company with the co-operation of the National Advisory Committee for Aeronautics. Its object is to obtain aerodynamic data at high speeds, often above the speed of sound, to aid the development of future high-performance aircraft.[2]

As originally developed, the "Skyrocket" was equipped with both a jet-engine and a rocket motor. The jet-engine enabled it to take-off, operate and land under its own power; the rocket motor was to supply the extra boost necessary for high-speed testing. A Westinghouse J-34 turbo-jet gave the machine its initial power and endurance, whilst the rocket unit, built by Reaction Motors, Inc., was of the same type as used in the Bell X-1; this unit is composed of four separate combustion chambers which each develop a thrust of 1,500 lb. The fuselage tanks contain 250 gallons of petrol (not kerosene, the more usual "jet" fuel) in addition to a supply of liquid oxygen and alcohol for the rocket motor. A hydrogen-peroxide pump, similar to the V2 unit, feeds the rocket propellant to the combustion chambers.

Weighing nearly eight tons fully loaded, the "Skyrocket" has a wing-span of 25 ft. and a fuselage length of 45 ft. (The speed of sound varies with temperature and is 761 m.p.h. at the average sea-level temperature, reducing to

DOUGLAS "SKYROCKET."

663 m.p.h. at 40,000 ft. where the air temperature is about 65 degrees. The speed of sound at any altitude is referred to as a Mach number of 1·0).

To obtain information on the behaviour of the aircraft at high speeds, 625 lb. of special instruments are carried, including a manometer that measures air pressure at 400 points on the wing and tail surfaces. Control forces and stresses in the structure are measured by means of 904 strain gauges and automatically recorded by an oscillograph. Five cine-cameras are provided to film the readings of a battery of special flight instruments.

Although tests with the "Skyrocket" have been made under varying conditions and at various altitudes, a typical procedure had been to take-off with both the jet-engine and rockets in operation, climb to 25,000 ft. with the turbo-jet alone, re-light the rocket motor and make the desired test run. One-and-a-half tons of propellant were consumed during the short time the rocket motor was functioning.

The "Skyrocket" first flew early in 1948 and proved an immediate success. However, to obtain even higher performance, Douglas was authorized in November, 1949, to continue the test programme by launching the exploratory craft *in the air*. This would enable the aircraft to operate in the upper atmosphere where the air offers less resistance. The efficiency of the jet-engine begins to fall off at these altitudes and consequently, the Westinghouse engine and its fuel system were stripped out to provide additional space for rocket propellant.

In a typical air-launching, the "Skyrocket" is attached partially within the bomb-bay of a B-29 Superfortress, which had been suitably modified to receive it; a crew of nine occupies the bomber.

The pilot enters the pressure cabin of the research 'plane shortly after take-off, prior to the bomber attaining altitudes where he would require auxiliary oxygen for breathing. The Superfortress climbs to altitude, and levels out at 35,000 ft.; two conventional jet-aircraft fly nearby, their crews acting as test observers.

After about an hour slung under the bomber, the "Skyrocket" is released in much the same way as a bomb, dropping away in a level attitude with power off. When safely clear of the B-29, the pilot switches on two or more chambers of the rocket motor and, after a brief level run, he pulls the 'plane up into a steep climb which rapidly brings him to altitude. The motors are then cut out and the machine is allowed to coast over the hump of the trajectory; all four chambers of the motor are then fired and the all-burnt condition and maximum speed are realized at the end of a shallow dive. In one record flight the "Skyrocket" achieved a speed of 1,327 m.p.h. (more than Mach 2·0)* at a height of more than 70,000 ft for 5 to 10 seconds. The greatest height so far is the 83,235 ft. altitude achieved by Lt.-Col. Marion Carl in the "Skyrocket" recently. In this flight, the rocket 'plane was borne aloft in the belly of a B-29 to 33,500 ft. After dropping down to 28,000 ft. (due, in part, to a faulty rocket chamber), the 'plane was accelerated in a 40-degree climb to the point of cut-off at 75,000 ft. From there on, the Douglas research 'plane "coasted" to its 83,235 ft. On this occasion, the pilot was wearing a full pressure-suit for protection in the event of failure of the cockpit pressurization system. At the zenith of the climb, the pilot had more than nine-tenths of the atmosphere beneath him: he was already on the fringe of space!

After the test, with all propellant exhausted, the pilot makes a spiral descent, and the machine (now lightly loaded and acting as a glider) is landed on the desert bed of Muroc dry-lake.

The "Skyrocket" (three of which have been built) has been succeeded by the Douglas X-3, which first flew in October, 1952.[3,4]

This twin-jet machine has a slender fuselage with an extremely long, tapered nose and short wings set well back towards the tail. Its length is no less than 66 ft. 9 in.—almost three times as much as the span of 22 ft. 8 in. The X-3 is, in fact, longer and heavier than the DC-3 transport, whilst the span of its wings is less than the transport's tail-span.

According to official sources, the X-3 is designed for a speed of Mach 3·0. Because of its present power plants, two Westinghouse J. 34–17 turbo-jets with afterburners (totalling only 9,000 lb. thrust), it is doubtful whether the machine will match in performance the rocket-powered "Skyrocket." Plans are in hand to replace these engines as more powerful units become available (two J. 40's totalling over 17,000 lb. thrust and probably rocket booster also).

Before it was built, more than 60 individual designs with all potential supersonic power plants—turbo-jet, ram-jet and rocket—separately and in various combinations, were considered.

** It appears that final guidance is obtained by the technique known as "passive homing" whereby the missile responds to target reflections from the ground radar. This enables the missile to fix its position in space and by means of an appropriate control system, to guide itself automatically to the source of reflected energy.*

The X-3 is primarily a flying aerodynamics laboratory and, as such, carries 1,200 lb. of research instruments. More than 850 "pin-hole" orifices record pressures over various portions of the aircraft; temperature readings are obtained from 150 points, while stresses and air loads are indicated by 185 electric strain gauges. Chief trouble will be high temperatures caused by aerodynamic heating, which at Mach 3·0 can reach 500° F. at extreme altitude, rising to well over 1,000° F. at sea level.

The greatest *speed* so far attained by a piloted aircraft was obtained last December with the Bell X-1A, a descendant of the original machine, which exceeded Mach unity in 1947. The pilot was (as then) Major Charles E. Yeager and the speed he achieved is officially given as 1,635 m.p.h. (Mach 2·5).

The X-1A is slightly larger than the original XS-1 and can be distinguished by the raised cockpit canopy. The original aircraft has a flush cockpit canopy.

Although the new machine retains the same power unit (built by Reaction Motors, Inc.) consisting of four separate combustion chambers with a total thrust of 6,000 lb., it has double the propellant capacity of the XS-1. Its all-up weight is 18,000 lb. (7,000 lb, empty) against 13,000 lb. Another refinement is that the nitrogen pressure feed system has been replaced by a turbo-pump. The motor burns an alcohol-water mixture and uses liquid oxygen, and is regeneratively cooled. The endurance under full power is 4·2 minutes.

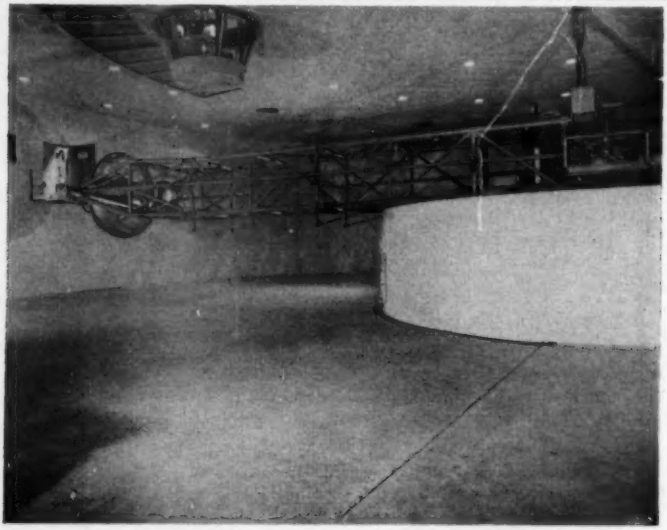
On the occasion of the record flight, the machine was air-launched at 30,000 ft.; three chambers of the rocket motor were fired during the climb to 45,000 ft., when the fourth chamber was cut in. The X-1A flew in an arc to 70,000 ft., where the pilot levelled out, reaching maximum speed a little above that altitude. During the speed run, the outside air temperature was −70° F., but the 'plane is reported to have got a "little hot" through air friction. A refrigeration system was not installed.

The X-1A was able to glide back to base without power boosting. In fact, residual propellant was jettisoned to avoid stability troubles during the glide. The aircraft lands at 150 to 160 m.p.h.

Another newcomer in the field of high-speed research is the Bell X-2, a swept-wing successor to the X-1A, which has stainless-steel wing and tail surfaces and a nickel-alloy fuselage, both to withstand aerodynamic loads and high skin temperatures due to skin friction. It is powered by a Curtiss XLR-25 rocket motor, the thrust of which is controllable by a throttle. Like the "Skyrocket" and the X-3, its cabin is air-conditioned and can be refrigerated to cool the cockpit at supersonic speeds and heated when operating at extreme heights.

Unfortunately, the first machine of this type was lost after an explosion which occurred in the bomb-bay of the Superfortress when it was climbing to the release altitude. A second X-2 was due to be tested early this year, but details are not available.

Both Bell and Douglas are reported to be working on methods to alleviate the effects of skin friction at high-Mach numbers. One idea being tried experimentally by Bell involves the ejection of small quantities of liquid helium at the leading edge of the wing, thereby lubricating the skin surface and reducing heat transfer to the wing structure by about 50 per cent. Other schemes involve refrigerating the leading edge of the wings, as well as the cabin.



The gondola is mounted in a 2-gimbal system, the inner and outer shell being constructed of aluminium, with a middle layer of a hard porpous plastic material called Strux. The gondola is equipped with physiological sensing devices, television cameras and both X-ray and motion-picture cameras to study the subject while the gondola is in motion.

From powerful research aircraft such as the "Skyrocket and the Bell series will gradually emerge the first primary "spaceships" capable of making short trips into space and diving back into the atmosphere, affording experience of the human reactions to "zero g" over increasingly long periods. Here, aerodynamic heating will be one of the most serious problems. The Bell X-2, with its stainless-steel and nickel-alloy construction comes closest to the type of vehicle that will be required to operate between the terminal orbit in space and the Earth's surface. It we imagine this aircraft as the top step of a three-step rocket, we can see more clearly how present-day aerodynamic research is contributing to astronautical development.

The first "space-suit"

A pressure suit, which will enable pilots to travel in safety in the extreme upper atmosphere—or even in space itself—has recently been announced by the U.S. Navy. Made of rubber, with a Plexiglas helmet, and containing its own oxygen and pressure systems, the suit gives full protection above 50,000 ft., where "explosive decompression" of the pilot's body in the event of loss of cabin pressure would otherwise result in death within a few seconds.

The need for pressure suits which, in effect, give the pilot his own life-saving atmosphere at altitudes where he would otherwise perish, has been recognized for several years. Many previous attempts have been made to develop such equipment, but other suits have been less than satisfactory either because they offered only partial protection, or because they were too cumbersome. The new pressure suit solves both these difficulties. It ensures that no matter what happens at altitude to the aircraft's pressure system, the pilot is safe to complete his mission. In the event of an emergency, the suit takes over automatically, pressurizing itself and furnishing oxygen to "supercharge" the wearer's lungs without any action on the part of the pilot.

The suit, developed for the U.S. Navy by B. F. Goodrich Co., is one of several now being developed in the United States to protect pilots of high-altitude research aircraft, such as the "Skyrocket," and for service use in the next generation of long-range bombers. Operational equipment will combine suit, helmet, oxygen mask, earphones, microphone, goggles and an emergency oxygen bottle, ensuring that pressure is maintained even under "bale-out" conditions.

A human centrifuge

Research into the physiological mechanisms which are critically affected by magnitudes and types of acceleration produced in military aircraft have been limited in the past by the performance of available centrifuges. With the completion of the human centrifuge at the Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania, it has become possible to extend previous research and to evaluate more thoroughly the tolerances of men and animals to acceleration, and to study the physiological systems which limit these tolerances.[2] (Illustrated opposite).

The principal feature of the human centrifuge is its ability to attain a maximum accelerative stress of 40 g. (40 times gravity) in less than seven seconds from standstill. The device consists of a 50-ft. rotor arm with a sealed gondola

in which the man under test is strapped in a typical aircraft seat; the arm is driven by a vertically-mounted General Electric d.c. motor weighing 180 tons, developing 4,000 h.p. A gimbal system permits the gondola to be rotated at any time to simulate turns, dives and pull-outs of an aircraft. The gondola is also equipped for temperature ranges from 44° F. to 110° F. and may be decompressed to approximate atmospheric conditions at an altitude of 60,000 ft.

Physiological studies of the subject are made possible by sensing devices which record measurements of his respiration, heart rate, blood pressure, heart and brain waves, from a remote observation station. Other equipment inside the gondola is a television camera, with monitoring receivers positioned at various locations inside the Laboratory, and high-speed X-ray and film cameras. All recording equipment housed in the gondola are linked to control and observation stations by means of slip-rings on the rotor shaft of the centrifuge.

The first floor is composed largely of modern subsidiary laboratories which contain two small centrifuges with 8-ft. and 3-ft. arms respectively, a physiology laboratory, chill room and electronics laboratory. The second floor houses the main piece of scientific equipment—the human centrifuge. The entire chamber, which has a diameter of 110 ft., is sheathed with 1/16th-in. copper to eliminate electrical interference with the intricate equipment used in the gondola. The control blister, observation room and recording facilities, are located on the third floor.

To increase the utility of the centrifuge, three free-swinging cars have been constructed and attached to the rotor arm at 23, 30 and 37 ft. suspension points so that several experiments can be conducted simultaneously. These cars are used primarily for engineering tests of equipment such as radio, radar and other electronic devices used in aircraft and missiles.

The smaller centrifuges are used to test the effects of acceleration stresses on small mammals, such as rats and mice. In such experiments, the subjects are frozen solid at the instant of attaining a certain desired accelerative stress by funnelling liquid nitrogen into the centrifuge whilst it is in motion. This technique—known as the "quick-freeze" method—permanently positions the internal organs at their maximum displacement, allowing accurate studies to be made of the effects on the organ structure, and also permits measurement of fluid shifts within the body.

In one test on the human centrifuge, five of the Laboratory's staff were subjected to 15 g. (15 times the force of gravity) for 5 seconds, accelerating from zero to 120 m.p.h. in 1½ seconds. Two of the men developed a few tiny blood blisters on their backs, which was all there was to indicate they had endured the highest gravity stress for the longest time that humans had sustained intentionally.

Research in the High Atmosphere

The sounding rocket is the immediate predecessor of the space-vehicle and, within a comparatively few years, it has been developed by the Americans as an important research tool in the upper atmosphere, far transcending the reach of pilotless sounding balloons. These balloons, which carry special light-weight radio-transmitting instruments, have enabled investigations of the

Earth's atmosphere to be made up to heights in the neighbourhood of 25 miles. The rocket, which has been the means of extending investigations to the outermost limits of the atmosphere, has been one of the most important scientific developments of modern times.

Research engaging the attention of scientists at the present time concerns cosmic radiation, the ionosphere, the spectrum of the Sun, and measurements of pressure, temperature and composition of the upper atmosphere. These studies seek answers to such questions as the changes in the Earth's magnetic field at high altitudes which affect navigational instruments; the alterations in radio waves caused by the ionosphere, the effects of sun-spots on communications equipment, and—something of vital concern to the operation of manned space-stations and spaceships—the nature of primary cosmic radiation. A great deal is also being learnt of the nuclear reactions which occur in the upper atmosphere due to bombardment by these high-energy particles.

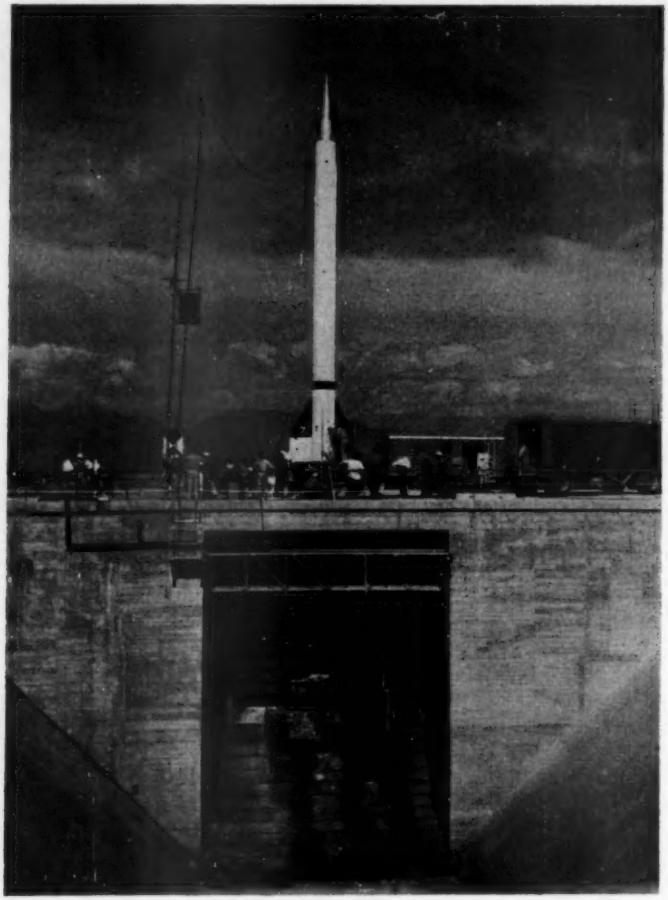
As we have seen, the first attempts to project recording instruments above the balloon limit were made in 1945 with a small American-designed rocket known as the WAC Corporal. This slim three-finned projectile, 16 ft. long by 12 in. in diameter, has a gross weight of 665 lb. With the assistance of a Tiny Tim booster, it ascended 43½ miles.

In 1946, a new high-altitude rocket was designed, similar to the WAC Corporal in general layout but with superior performance and more space for instruments. This was the "Aerobee," a joint project of the Aerojet Engineering Corporation and the Douglas Aircraft Company, with supervision from the Johns Hopkins University. This bi-propellant rocket, which has an overall length of 18·8 ft. and a diameter of 1·25 ft., is fired from a 140-ft. tower with the assistance of a solid-propellant booster. The booster jettisons within a second of firing, after accelerating the projectile to a speed of about 1,000 ft./sec. Propulsion of the "Aerobee" continues for 45 seconds and at the climax of the thrust period, the rocket's velocity is approximately 2,790 m.p.h. and the altitude attained, about 95,000 ft. Summit altitudes of 70 to 80 miles have been achieved on several occasions since the first successful firings in 1948.

Like its predecessor, the vehicle is unguided and relies on "arrow stability" derived from a high launching velocity, its three fixed fins and proper location of the centre of gravity. Its trajectory is controlled simply by tilting the launching tower in accordance with wind data obtained from meteorological balloons.

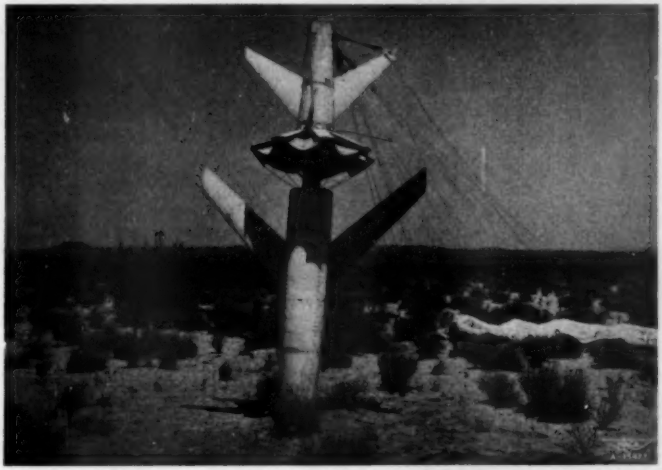
Flight data was originally retrieved from the rocket by two methods: (*a*) by radio telemetering, and (*b*) by recovery of specially armoured equipment from the impact wreckage. Explosive separation of the nose-cone from the body of the rocket was arranged to occur at a suitable altitude on the descending path of the trajectory. The nose section, containing the instruments, was thus made aerodynamically unstable, with the result that it tumbled to earth relatively slowly and certain equipment, cine-cameras, etc., were satisfactorily recovered. More recently, it has been possible to land the complete instrument compartment by ribbon-type parachute—a procedure which proved successful in the recovery of mammals in the recent "weightlessness" experiments.

When rockets were required to penetrate 100, 150, 200 miles and more, to



THE "VIKING" ROCKET.

the very threshold of space, it was obvious that the design problems would become increasingly complex. To investigate these problems and at the same time produce a useful research vehicle, the Naval Research Laboratory issued a contract to the Glenn L. Martin Company for the construction of ten rockets with the ultimate aim of ascending 200 miles.[1] These rockets, called "Vikings," were produced in series, and each succeeding design profited from experience gained from the previous firing. At the time of writing, eight "Vikings" have been launched, seven of them at White Sands, New Mexico, and one from the



Successful recovery of a free-falling "body" after a drop of nearly seven miles is illustrated by this photograph. Its descent first checked by automatic dive brakes (seen open) and then by the parachute which is shown to the right, the body is buried nose first in the sandy soil of the California desert. The model wings are undamaged and the instruments and the records they made during the fall can be recovered intact.

deck of the U.S.S. *Norton Sound* in the Pacific south of Hawaii; the eighth vehicle of the series was abandoned during development, its features being carried over to the ninth, which embodied further refinements.

All the "Vikings" have been powered by a rocket motor developed by Reaction Motors, Ltd., which achieves a thrust of 20,500 lb. from the combustion of liquid oxygen and alcohol.

The "Viking" has no booster and takes off from a simple platform, in the same way as the German V2. To achieve stability during the initial moments of the ascent, when the airflow relative to the rocket is insufficient to react on the fins, a system of thrust control is employed. The rocket motor is mounted on gimbals; under the control of gyroscopes the motor can be moved to steer the vehicle in pitch and yaw. Thus the exhaust stream is deflected—and the thrust momentarily offset—to oppose any deviation from the flight path.* A similar system in which gyro-controlled vanes worked in the exhaust gases, was the secret of the remarkably slow yet perfectly controlled ascent of the German V2.

The nose of the vehicle is instrumented in the usual way with electronic equipment which transmits information to a ground station where it is recorded on moving tape for future study.

The design of the ninth rocket represented a departure from previous "Vikings" of the series, which ranged from 45 to 48 ft. long with a diameter of

* A system of control pioneered by Dr. R. H. Goddard in 1937.

32 in. The redesigned version had a length of only 42 ft., but the diameter was enlarged to 45 in. to accommodate 50 per cent. more propellant; the fins too, were smaller and triangular-shaped. New control, propellant and electronics systems were embodied.

The nose section, including the cone and a proportion of the cylindrical body, contained equipment for measurements in the ionosphere, telemetering, and the majority of the Naval Research Laboratory's payload. The forward nose section is sealed at ambient take-off pressure and is made completely accessible by means of an interrupted thread connection which allows removal of the conical skin. The aft nose section was not sealed, but access was provided by removal of four non-structural doors comprising the entire skin in that area. Structural materials are almost exclusively aluminium-alloy with the exception of plywood webs and bulkheads for convenience of mounting instrumentation. This complete nose section is separated from the rocket afterbody by explosives on the descending leg of the trajectory. The two unstable portions tumble upon re-entry into the atmosphere, producing sufficiently high drag that the extent of damage at impact is surprisingly small.[5]

The next section aft of the nose contains the integral alcohol tank and houses the gyroscopes at its forward end. The structure is pure monocoque, welded aluminium-alloy except for a short section on the forward end which distributes concentrated nose loads. Like the forward tank, the liquid oxygen tank is integral, such that the rocket skin forms the tank wall, and is of pure monocoque, welded aluminium alloy construction. An external conduit carries wires from the nose to the tail section and to the ground disconnect plugs.

The aftermost portion of the rocket contains another instrumentation section for research equipment, the turbine-pump assembly, tanks of hydrogen peroxide for driving the turbine and furnishing control, the majority of control system components, propellant plumbing and valves, and, of course, the power-plant. A large number of doors, amounting to approximately half the skin area in this section, permit access to all components. Within this section, thrust loads are distributed to the skin, and fin reactions are absorbed by the rocket.

The fins, of a modified double-wedge aerofoil shape, are of single spar, conventional skin-rib construction. The material is basically aluminium-alloy with some steel in the spars and with magnesium tabs on the outboard tips.

The extensive use of aluminium in the construction of "Viking" enables the take-off weight to include no less than 80 per cent. propellant, which compares with 67 per cent. for the V2 and 55 per cent. for "Aerobee."

Although designed for a maximum payload of 2,000 lb., "Viking 9" carried 750 lb. of instruments, some of which were intended to measure sunlight in various X-ray and ultra-violet regions of the upper atmosphere. The instrumentation included a spectrograph which was automatically pointed at the sun, three photon counters and photographic film detectors. (It was with a film detector that X-rays were first discovered in the atmosphere by scientists of the Naval Research Laboratory several years ago). Photon counters are similar to the more familiar Geiger counters used to detect atomic radiation except that they count individual light particles (photons) instead of electrons (protons) or

heavy nuclei. The purpose of the photon counters and film detectors on the recent flight was to analyse the sunlight and measure its quantity accurately.

Specially prepared photographic emulsions were located in the nose of the rocket to detect cosmic radiation. The vehicle also carried six cameras to determine the orientation of the experimental equipment during flight and also to obtain wide-area infra-red photographs of the Earth's surface.

The majority of the information was obtained by means of radio telemetering, the particular system used having 30 channels which enabled coded signals to be sent continuously and automatically to a ground receiving station. In this way, it was possible to record information on the flight characteristics (rocket motor performance, missile aspects, etc.) in addition to fulfilling the rocket's primary task as a research tool in the upper atmosphere.

Under the direction of the Naval Research Laboratory, the present aims of the "Viking" programme are to extend knowledge of: (*a*) the physical state of the Earth's atmosphere to as great an altitude as possible; the principal objects of study being temperatures, pressures, densities, and composition, (*b*) the fundamental nature and properties of the ionosphere and those processes which lead to its formation; (*c*) solar and terrestrial radiations; and (*d*) the physics of high-energy particles by high-altitude cosmic-ray studies.

The "Viking" programme has for its ultimate aim the development of a vehicle to extend measurements of the upper atmosphere to 200 miles, and following the firing of the ninth version, the Naval Research Laboratory placed an order for four additional rockets, making the total 14.

Experiments were made during 1952–53 to develop a technique for launching a small rocket from a plastic "Skyhook" balloon.[6] The method has proved an inexpensive means of projecting small instrument loads into the upper atmosphere, and in August, 1953, a payload of 30 lb. was carried to an altitude of approximately 60 miles, the rocket having been released from the balloon at a height of 50,000 ft. This compares with a peak altitude of 100,000 ft. (19 miles) which the rocket achieved at White Sands in a vertical firing from the ground. In this way, the high drag due to firing through the atmosphere is avoided, and almost the theoretical vacuum performance of the rocket can be realized.

The 9-ft. rocket, known as the "Deacon," and manufactured by the Alleghany Ballistics Laboratory, employs a small solid-propellant "JATO" unit, which produces a thrust of 5,700 lb. for 3·5 seconds. Instruments are housed in a detachable nose section.

The "Deacon" is carried in a light sling beneath the balloon on a 100-ft. cord, and a small box containing a timer, a barometric pressure switch and firing batteries, is suspended from one of the rocket's fins.

The balloon takes about 60 minutes to reach 50,000 ft., whereupon the barometric switch fires the rocket automatically, the connection with the firing box being severed by the violence of the acceleration.

The experiments have been sponsored jointly by the Office of Naval Research and the Atomic Energy Commission in conjunction with the State University of Iowa, and are primarily intended for cosmic ray studies. For this purpose, the rockets carry either Geiger counters or ionization chambers whilst, in some

tests, the balloons have been used alone to carry nuclear emulsion plates, which measure the passage of cosmic rays at heights in the region of 90,000 ft.

Launchings have been made from the U.S. Coast Guard Icebreaker, *East Wind*, in the vicinity of the Northern Geomagnetic Pole.

In comparison with expensive ground-launched rockets, the rocket balloon combination comes out as an extremely economical proposition. The "Deacon" itself costs approximately £280, the balloon £140, with the total cost per flight, including instrumentation, well within the sum of £1,000. Even the simple "Aerobee"' which is capable of lifting a 150-lb. payload to a height of 75 miles, costs nearly £9,000—without instrumentation; a figure as high as £143,000 has been quoted for the much larger "Viking."

Individual experiments sometimes demand different techniques, and to obtain direct measurements of temperature in the upper atmosphere, instruments have been ejected from the rocket-head independently. This technique has been developed in experiments by the Army Signal Corps to determine the exact temperature a body will reach in the region between 55 to 75 miles above the Earth. Rocket soundings have indicated that at about 55 miles altitude, the temperature increases from minus 28 degrees and may reach 400° F. at a height of 400 miles.

The new method employs an inflated sphere which is released from an "Aerobee" at an altitude of 80 miles.[7] The sphere, initially only partly inflated, is carried in a wooden cylinder just behind the nose-cone of the rocket. Near the peak of the trajectory, the partially inflated sphere is ejected: air from a small pressure cylinder expands it to a diameter of 4½ ft. Temperatures in the upper atmosphere can be determined by measuring the rate of fall and a small radio transmitter, enclosed in the sphere, sends continuous signals to a ground station, where the data is recorded. The sphere is manufactured of neoprene-impregnated nylon, 1/15th of an inch thick, by the Goodyear Tire and Rubber Company. These studies are expected to help in the investigation of atmospheric changes, long-range radio communication, and the design of new operating equipment.

One of the most important developments in the period under review was, of course, the experiments carried out with mammals under conditions of high acceleration and zero-g.

The United States Air Force disclosed in 1952 that mammals were recovered alive and unharmed after being fired to approximately 200,000 ft. in the upper atmosphere in an "Aerobee" rocket. The purpose of the flight was to provide information on the reactions of mammals under conditions of zero-gravity and extreme altitude, and two monkeys and two mice, the mammals involved, were recovered alive and in good health after the tests at Holloman Air Force base.

The subjects experienced no unusual effects from the flight, although they were subjected to a brief initial acceleration of about 15 g. lasting less than a second, and a longer force of 3 to 4 g. lasting for 45 seconds.

In publishing full details of these experiments. the *Journal of Aviation Medicine* has revealed that three "Aerobees" were employed.

The nose sections were equipped with ribbon-type parachutes, in the hope that the entire rocket head, containing both the instruments and the animals,

could be recovered. Unfortunately, there was no successful parachute recovery in the case of "Aerobee" 1; modifications were introduced into "Aerobee" 2 and this system, with minor adjustments, was used with success in "Aerobee" 3. In "Aerobee" 1, satisfactory data was received up to the point of impact.

The experiment using the anæsthetized monkeys was the first attempt at telemetering physiological data from high altitudes. Tables of pulse, respiration and electrocardiograms obtained showed remarkable evidence of freedom from disturbance.

The mice travelled without an anæsthetic and had complete freedom in their chamber. An automatic cine-camera was provided to record their behaviour and apart from one case in which part of the balance mechanism of the inner ear had been removed, no attempt was made to determine biological reactions. When the film was recovered the mice were shown to have acted normally up to the time propulsion ceased, but during the three-minute period of zero-gravity, one is seen threshing about in mid-air while its companion, who can grasp the sides of his platform, is able to maintain his equilibrium. As Dr. Henry has pointed out, the mice were apparently as much at ease when inverted as when upright; they merely lost the vertical reference of gravity and assumed whatever posture was convenient. The conclusion from this experiment is that gravity sense is lost if there is no way of keeping in one place. In other words, mammals who are able to hold on to something can orientate themselves and be little affected by the zero-gravity period.

The development of the orbital rocket must be awaited before the effects of zero-gravity lasting many hours can be investigated.

Guided Missiles

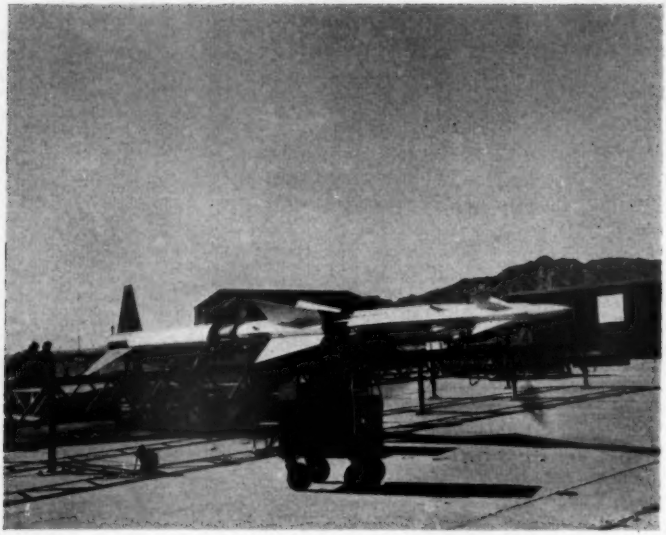
The "Nike," developed for the U.S. Army by Bell Telephones in association with Douglas and other companies, was the first post-war surface-to-air missile to enter full production.[1] The missile embodies triangular wings and steerable nose vanes and is launched with the aid of a powerful booster.

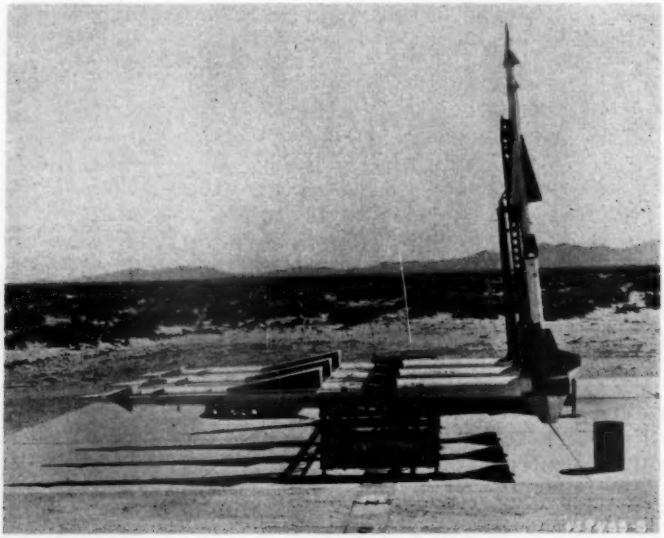
Tested at White Sands in the Spring of 1953, "Nike" successfully scored a direct hit on a QB-17 target drone flown under remote control at 30,000 ft.

Tracked by radar, the bomber approached the launching site trailing smoke from a flare on its starboard wing, which had been fitted to assist ground observation and photography; when it came within range, an operator moved a switch which fired the "Nike" from an elevated ramp. Another radar set locked on to the missile as it accelerated away. The two plots from the bomber and missile were then continuously integrated by an electronic computor, which caused steering signals to be sent to the missile, changing its course until the radar traces signified that the "Nike" was nearing its objective.

The missile struck the bomber at a point beneath the starboard wing, the violence of the explosion causing its instant destruction; as part of the wing began to crumple, the outboard engine ripped away and was followed shortly by the inboard engine as the stricken aircraft rolled over and over with flames spurting from its fuselage.

When earlier tests had been made in conjunction with a radio-controlled QB-17, "Nike" had been fired with a warhead of smoke-generating powder





The "Nike" can locate and destroy enemy aircraft by means of an electronic "brain" regardless of evasive action. The missile was developed for Army Ordnance under contract by Western Electric Company, which manufactures the guidance and control system developed by Bell Telephone Laboratories. The missile itself was designed and is manufactured by Douglas Aircraft Company.

instead of explosive. This enabled the missile to be recovered by parachute and the bomber—dirty but intact—to return to base.

"Nike," so-called after the Greek goddess of victory, is said to have a range of approximately 17 miles. Several variations of the missile have appeared, with different types of in-line boosters (one with "wrapped" boosters, in addition) and the finalized weapon was being installed, in the early part of 1954, at various key centres in the United States; the first site is to be at Fort Meade, Maryland (between Baltimore and Washington).

Whilst the amount of guidance equipment carried in the "Nike" is comparatively small—being essentially a receiver and appropriate servo-mechanisms for working the controls—the ground equipment is exceedingly complex and contains no fewer than 1,500,000 individual parts. However, by building the "brains" of the weapon into the ground equipment, so that as little as possible is lost with each missile, the Americans have achieved a comparatively cheap anti-aircraft missile, although one necessarily limited in range.

The "Nike" itself represents an early stage in the United States missile programme, being originally test fired in 1946. Other A.A. missiles, beam-riders and self-homing types depending on both radar and infra-red homing are known to be in an advanced stage of development.

In recent years, France has also become prominent in the field of guided-missiles. The Matra M.04, one of the more interesting projects, has been developed by SNCA du Sud Est and Société Matra* for the French Air Force. Described by the manufacturers as a two-thirds scale model of a projected anti-aircraft weapon, the Matra M.04 has a length of approximately 15 ft. with cruciform wings of nearly 6ft. span and cruciform tail fins. The rocket motor, of S.E.P.R. manufacture, delivers a thrust of 2,750 lb. for 14 seconds.

The missile has an all-metal construction with magnesium frames and duralumin skin. The two propellant tanks are fabricated from sheet steel by welding, and have a total capacity of 242 lb.

Fuel and oxidant are pressure-fed to the combustion chamber by compressed air obtained from two annular storage tubes, when membranes in the tubes are pierced by electrically-operated pins.

In tests carried out at an Air Force range in the Sahara in 1952, the Matra M.04 was released from beneath the fuselage of a Handley-Page "Halifax." Usually, the test altitude was 13,000 ft. and the release velocity, 260 m.p.h. The missile was allowed to drop a short distance from the aircraft and 5 seconds after release, the motor was started automatically, wherepon the missile accelerated rapidly to reach a maximum speed of about 1,100 m.p.h., remaining at a constant height during the period of propulsion. After losing speed, the missile glided to a height of approximately 2,600 ft. when a radio altimeter released an instrument capsule.

The instruments are capable of recording 24 different reactions throughout the entire period of thrust and provide complete data on the behaviour of the auto-pilot and control responses at all speeds. The test missiles are recoverable by parachute and are usually retrieved without major damage.

Several auto-pilots and a variety of wing and tail configurations have been

* Société Generale de Mecanique, Aviation, Traction.

tested since 1950, when the first launchings were made, performance being compared at each stage; however, more than a year elapsed before supersonic speed was attained with the desired stability.

Further air-launchings have since been made with a Grognard twin-jet fighter in which the missiles are mounted on under-wing racks. Test firings of a wingless missile have also been made from the ground in conjunction with a solid-propellant booster.

The rapidly expanding guided-missiles industry in the United States, accelerated by the transfer of "Nike," "Terrier," "Corporal E," "Regulus" and "Redstone" to production status. is continually bringing new manufacturers into the field. Prominent among these is the Firestone Tire and Rubber Co., who have received a production contract for a substantial quantity of the "Corporal E" surface-to-surface missile.[1]

Developed at the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT), this new Army Ordnance weapon bears an outward resemblance to the WAC Corporal, a former GALCIT project, but is considerably larger and has complete radio-guidance; it is believed capable of carrying an atomic warhead. Prototypes were produced by the Douglas Aircraft Corporation.

Among other manufacturers of artillery-type missiles is the General Electric Company; this firm has been engaged on rocket motors and associated equipment since 1945 and is sponsoring the Hermes project. This programme has broad objectives which included A-4 firings as well as basic research on rocket units and propellants and the fabrication of complete test vehicles. One of the first G.E.C. missiles, the Hermes A-1 is a development of the German Wasserfall in a surface-to-surface rôle.

The latest missile in this class, and possibly the most significant—since its development has been in the hands of Dr. Wernher von Braun and other German rocket engineers from Peenemunde—is the "Redstone," a long-range surface-to surface rocket, which successfully completed tests at White Sands in 1952. Dr. von Braun is technical director of the Army Ordnance Guided-Missile Development Group, Redstone Arsenal, Huntsville, Alabama, from which the project derives its name. Few details of the rocket are known except that it is larger than the V2 and that its production will be carried out by Chrysler's of Detroit.

However, knowing something of von Braun's tactics, one can be fairly certain that in the top drawer of his desk at Redstone Arsenal, there are detailed plans for converting this formidable military weapon into a primary "spaceship" at short notice.

The fact that these new weapons have entered production indicates that some of the problems, particularly those affecting guidance and control, are being overcome, and the ground is surely being laid for the long-range step-rockets which Dr. von Braun envisaged to succeed the A-4. Meanwhile, the gap between the short-range rockets represented by these projects and the inter-continental missiles envisaged will be filled by such types as the Northrop XB-62 "Snark," which the Americans prefer to call "pilotless bombers"; having turbo-jets to secure the necessary range, and depending on automatic

star-tracking navigation, these, of course, lack the ability to operate at the high Mach numbers which would render them virtually invulnerable to enemy interception.

The Future and Astronautics

At a recent meeting of the American Rocket Society, Dr. Von Braun gave a lecture on "The Need for a Co-ordinated Space-Flight Programme," which shows that his views have been tempered considerably since his big publicity drive for astronautics began in *Collier's Magazine* two years ago. He pointed out that there are two schools of thought on the subject of space-flight. First, there was the extremely cautious group who would put the time for even the first orbital rockets at sometime in the next century, and second, those who would have us rush out into space immediately. Von Braun indicated that his position was somewhere between these two extremes and went on to say that while admittedly the road is long and hard, and no one with a knowledge of the subject would say that we could leap from today's progress to that needed for space-flight, there was a definite place for long-range planning for the future. Among examples of what could be done now were propellant research, structural design of the various types of space-vehicles which would be needed, and most of all the production of suitable propulsion units in large enough quantities so that they could be tested and re-tested until they had the reliability of modern aircraft engines. He gave his opinion that the reason for the high percentage of failures in current rocket research was that each vehicle was powered by its own special, tailormade engine, and that little effort was being made to develop a standard reliable rocket engine for use alone, or in clusters, on many rocket missiles.[6]

In answer to those who claim that there is insufficient knowledge to even begin to map out a space-flight programme, von Braun pointed out that we already have most of the data necessary for putting an unmanned rocket into an orbit round the Earth. Finally, he dealt with the problems involved in a manned spaceship, including the greater payload, the necessity of returning the ship safely to earth, the biological questions, etc. He strongly recommended as a tool for studying these problems, a three-step unmanned rocket, fitted with telemetering equipment and containing several animals whose reactions to free-fall and prolonged exposure to cosmic radiation would be recorded and automatically reported to observers on the Earth, Such a rocket, he said, would circle the Earth at a distance of approximately 200 miles until, at the end of about two months, the very small air resistance at that height had slowed it sufficiently for it to plunge back into the Earth's atmosphere to be burnt up by air friction. The animals would be mercifully killed by gas poisoning before this stage was reached.

Since it is theoretically possible today to design and build instrumented rocket vehicles for both orbital and escape missions, one is often asked whether there is not justification for a space-satellite programme, such as the Americans suggested in 1948, but which they have apparently not followed up in practice. One reason, of course, is that such a project would be economically unsound in the present stage of world tension—with little military advantage. There is,

however, a second good reason why this has not been done. Anyone who is associated with the missile programme will be well acquainted with the failures that occur unaccountably during missile firings, perhaps on the electronics side—in guidance or telemetering—with the result that a particular test is completely useless. A satellite vehicle that suffered similar failure would be a costly item indeed; it need not be anything particularly dramatic—just a small electronic failure, perhaps, which prevented the vital information being telemetered from the rocket.

Consequently, there is great need to consolidate our development in the military field before embarking on more ambitious projects.

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DEVELOPMENT OF A LUNAR BASE

By G. E. V. Awdry

Few mining engineers seem to have joined the B.I.S., perhaps understandably. A layman can be forgiven therefore for considering some of the problems which will arise in the field of mining and metallurgy during the development of a lunar base, with a view to making this base as useful as possible, while keeping the cost in supplies brought in down to the minimum. The solutions advanced may or may not be valid, but these are real problems which call for attention.

It is assumed that a small permanent base has been established underground for scientific research, with the obvious laboratory and field equipment, and that plentiful electrical power is available, either from solar heat or nuclear energy. A regular, though infrequent shuttle plies between the Moon and an orbit about the Earth, so that anything worth the energy-cost can be imported. The base uses algae-tanks to replace oxygen consumed, and to grow its food, any wastage being made up by imports. The Moon itself is assumed to consist of complex silicates, similar to unweathered igneous rocks on Earth, probably with much uncombined silica, any volatile elements or stable compounds having been dissipated.

I am not competent to discuss mining in detail. But for some time the ores will be a by-product of excavations for additional living and storage space. The expedition must have come prepared to do some tunnelling, in order to get underground, so equipment will be available. The aim should be at first to use explosives as little as possible. Their transport will be an appreciable item. Meanwhile, a core-drill will be a better choice, say one of 6 in. diameter. The cutting-head should be tipped with tungsten carbide, or industrial diamonds, so that only these relatively light items need be imported as consumed.

Silicates are hard and abrasive, but mostly brittle, and wedges, thermal shock, or even hammers will probably serve to break down the working face once enough holes have been drilled. Later on, liquid oxygen will become available for blasting, and boring may be done with an iron pipe, burning in oxygen fed through it. This method is already in use, and will melt concrete. It should be particularly useful in association with thermal shock produced by injecting a little liquid oxygen afterwards. Tunnelling under these conditions will be heavy work, and should be carried out in an atmosphere, if the rock is firm, to avoid physical distress. Dust-respirators, however, will be essential, to prevent silicosis. None of this excavation will be wasted, as prudence will demand that the base be subdivided into sections connected by tunnels with emergency air-locks.

The simplest means of transport will be by suspended railway, at first with manual haulage, later electrified. This uses one rail instead of two, and fewer wheels as well—a considerable saving in metal at installation—though wear will be higher. It can be easily suspended from the roof, by something resembling the familiar Rawlplug. It will have a further advantage as the base becomes extensive and speeds rise, for such a system is naturally stable under centrifugal force on curves. The conventional railway depends on gravity, assisted by super-elevation of the outer rail, to resist this force, and lunar gravity is dangerously weak for the purpose, unless an impracticably broad gauge is adopted. In the reduced gravity, gradients need not be so carefully avoided, but some means will have to be found to increase adhesion at starts. Electrical drive applied to all wheels might suffice, or spring-loaded rollers underneath the rail which could be engaged or disengaged at need. Brakes should be of the electromagnetic sledge-type commonly used on tramways.

Silicates are unpromising ores by their abrasiveness, the large quantities needed for a given yield of metal, the close association of several metals in any one sample, and the great bulk of tailings. These latter present a less immediate problem on the Moon, being silica, which can be used as an insulator, or fused and formed into many useful articles, notably tanks and piping for ore-processing. It will be worth while to subject the tailings to heat treatment in any case, to recover the last traces of reagents and water. The first ore treated will be lunar dust, which will need no grinding. Later on, it will be possible to build an old-fashioned tube-mill, in which the larger lumps of ore will do the actual grinding, thus saving the need for hard-wearing steels at some cost in efficiency and time. But power is plentiful. The dust is leached with acids, and the liquor subjected to a series of selective precipitations, until it contains only sodium and potassium salts, when it can be concentrated and electrolysed to yield these metals or their hydroxides, which will be needed to leach out aluminium. Heat treatment, or electrolysis, will recover water or acids still locked up in the precipitates.

The various metals will call for different methods of treatment. Pure iron can be deposited electrolytically from a sulphate solution, if the bath is topped-up with iron oxide from time to time. Calcium, which may be useful as a bearing-metal under airless conditions, can be electrolysed out of fused oxide, magnesium from its chloride. Even aluminium can be plated out of a

non-aqueous solution with an admixture of lithium hydride. Wherever possible, to save reprocessing, metals should be deposited in moulds[1], so that the article needs only finishing. Where powder metallurgy can be used, this also makes a worthwhile saving in time and plant.

More conventional reduction processes call for greater thought. If enough alkali metal is readily available, aluminium can be reduced with this instead of carbon, while a simple cyclic process can be used to reduce iron. Hydrogen passed over heated iron oxide is partly oxidized, reducing the oxide to iron. Water vapour is extracted from the gas by metallic sodium, which reaction replaces half the hydrogen. The rest is recovered by electrolysing the sodium hydroxide formed, and the water evolved in this electrolysis.

It will be easier, however, if we can avoid using so elusive and bulky a gas as hydrogen as a reducing agent. The alternative is carbon, or its monoxide. By hypothesis, we have on the Moon no source of carbon such as coal, but we have in the algae tanks the means of fixing it from its dioxide, and the algae can be distilled to yield a reasonably pure carbon. Briquetted with the pitch that will be another product of this distillation and baked, this will provide usable electrodes for an arc-furnace. It will be necessary in any case to have extra tank capacity available, in case of breakdown at the base or sudden arrival of additional inhabitants, and it may as well be in constant operation. Possibly, the algae could be left in the dark, or otherwise kept dormant, but this is a waste of capacity when they can be put to good use. To maintain the cycle, the other distillation products must be oxidized and recycled, but that should be straightforward enough. On the basis of a recent paper, 1 litre of solution containing 55 grams algae produces a usable surplus of 2·5 grams algae daily. It is reasonable to suppose that 20 per cent. of this yield is readily recoverable as usable carbon,[2] so that 2 cubic metres of liquid will yield daily 1 kg. electrodes, enough to reduce, in theory, 3 kg. aluminium or 7 kg. iron (from a mixture of both oxides, quoted as a mean figure).

There are still considerable difficulties. In order to reduce worthwhile quantities of metal, very large tanks will be needed to recycle the carbon. Mining operations will soon provide space for these. Fluorine, or its compounds, are always found in the gases resulting from aluminium reduction, due to the breakdown of the cryolite used as flux. It should not be difficult to separate these off by inducing them to combine with some base or metal relatively inert to carbon dioxide. In case carbon monoxide is present, oxygen ought to be added to these gases while hot, and this may present technical difficulties. There will be an inevitable wastage of reagents used for leaching, and of carbon and water. Perhaps the ores themselves may yield enough of the latter, included as water of crystallization, but the others will have to be replaced. Sulphur may be present. If not, it can be imported, and converted to acid on the Moon. There will be no point in hauling up oxygen. Nitrogen, combined as hydrazine, is a likely rocket fuel, and prudence will indicate building up stocks, from which a little can be spared for conversion to nitric acid. If the chosen oxidant is nitric acid, it will be well worth while making this on the Moon from hydrazine, at least for the return trip. Fluorine is a constituent of some igneous rocks, but will otherwise have to be imported. Carbon is the most important

item, for there will be consumption as well as loss, steel containing up to 1·5 per cent. But a little ingenuity can be used here. Activated carbon is an excellent insulator for liquid oxygen tanks, but gelatinous silica—which leaching operations will produce in enormous quantities—is an acceptable substitute, and could replace it for the earthward trip.

Whatever else is scarce on the Moon, oxygen will be abundant. A tonne will be extracted in the reduction of 2·625 tonnes of iron, or of 1·125 tonnes of aluminium, 1,000 days' supply for a man, with no recycling. There will be leakage losses, but on nothing like this scale. The Moon will be able, therefore, to supply all space-craft and artificial satellites except those departing from Earth. It seems essential, also, despite the long transit time, to adopt ion-drive, at least for freight shuttles, between the Earth satellite and circumlunar orbit. Spitzer has shown that an acceptable performance can be achieved by a vehicle using nitrogen accelerated to 100 km./sec. as reaction-mass. Allowing for differences in atomic weight, the same installations would presumably accelerate oxygen to about 80 km./sec. This apparently gives a mass-ratio for oxygen equal to the 5/4 power of the "nitrogen" mass-ratio, which would be tolerable for a relatively short haul, and oxygen need not be brought up from Earth, as nitrogen would have to be. The ionizing grids might present some difficulty owing to the danger of corrosion. But one cannot imagine the United States promoting an export from the Moon which will only entail further excavations at Fort Knox, so that gold, if it is found, will be merely another metal, to be put to any use for which it is suited. Being very ductile, and a good conductor of heat and electricity, as well as being immune to oxidation, it should be an excellent material for ionizing-grids, if it can be adequately supported.

From this, it appears that the necessities of life and development can be made available without excessive cost, and that the hope of using the resources of the Moon to open the Solar System to exploration is a good one. The main obstacle will be time, for until enough development has been done to support a larger population any progress can only be gradual. But much can be done without massive equipment, and with the import only of essentials. Very few of these need be consumable stores.

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EFFECT OF TIDAL FRICTION ON A NEAR SATELLITE

By J. Logie

SUMMARY

A space-station revolving round the Earth below an altitude of less than 1,000 miles would need powerful engines to sustain it, otherwise tidal friction will bring it down to Earth in a few months.

The purpose of this research is to determine whether tidal friction will have any appreciable effect on the stability of a space-station erected at about 500 miles above the Earth. Only circular orbits will be considered. To remove doubts of their validity, the formulae used are developed from first principles.

The following symbols will be used:—

G	The gravitation constant	$6{\cdot}658$	10^{-8} dyne.cm.^{2}/gm.^{2}
m	The mass of a small satellite.		
M_E	The mass of the Earth	$5{\cdot}98$	10^{27} gms.
M_S	The mass of the Sun	$1{\cdot}9854$	10^{33} gms.
M_{Mn}	The mass of the Moon	$7{\cdot}33$	10^{25} gms.
r	The distance of satellite from Earth's centre		
R_E	Equatorial radius of Earth	$6{\cdot}3784$	10^{8} cms.
R_S	Sun's distance from Earth's centre ..	$1{\cdot}494$	10^{13} cms.
R_{Mn}	Moon's distance from Earth's centre ..	$3{\cdot}8441$	10^{10} cms.
ω	Angular velocity in orbit of satellite.		
ω_E	Angular velocity of Earth's rotation ..	$7{\cdot}2921$	10^{-5} rad./sec.
ω_S	Angular velocity of Earth in orbit about Sun	$1{\cdot}991$	10^{-7} rad./sec.
ω_{Mn}	Angular velocity of Moon in orbit ..	$2{\cdot}6616$	10^{-6} rad./sec.
I_E	Earth's moment of inertia about polar axis	$8{\cdot}1258$	10^{44} gm.cm.^{2}

It is a well-known deduction from Newton's third law of motion that if any number of masses interact on one another the forces they exert on each other cannot change the motion of their own centre of mass. Hence if two bodies of mass M and m move in circular orbits under their mutual attraction these orbits are centred upon their centre of mass. Hence if the distance separating them is r, M describes a circle of radius $mr/(M+m)$, while m describes one of radius $Mr/(M+m)$, with the same angular speed.

Taking this angular speed as ω the centripetal mass-acceleration of M is $M\omega^2 mr/M+m)$, and that of m is $m\omega^2 Mr/(M+m)$. These, of course, are both equal to the gravitational force GMm/r^2.

Hence

$$\omega^2 r^3 = G(M+m) \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

This equation holds true also for elliptic orbits, if for ω we put its mean value $2\pi/T$, where T is the period of one revolution, and for r the mean of its least and greatest values. A proof will be found in Smart's *General Astronomy*.

In the case of a space-station, m is so small compared to M that it may be neglected, giving

$$\omega^2 r^3 = GM_E \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1')$$

If $\omega = \omega_E$ there will be no tidal friction. Equation (1') shows that this can happen only at the distance $r = 6{\cdot}608\ R_E$, a little more than 22,000 miles above the Earth's surface. For greater values of r, ω is less than ω_E and tidal friction will drive the satellite out towards the Moon. For lower values of r tidal friction drags the space-station down to Earth.

The principle of the conservation of angular momentum gives us a second invariant, for the interactions of a group of masses among themselves cannot alter their total angular momentum about their own centre of mass.

The angular momentum of M is $I_M\omega_M + Mm^2r^2\omega/(M+m)^2$

and that of m is $\quad I_m\omega_m + mM^2r^2\omega/(M+m)^2$

where I_M is the moment of inertia of M, and ω_M is its speed of rotation, with a similar notation for m. Adding these, and noting from equation (1) that $r^2\omega = \sqrt[3]{G^2(M+m)^2/\omega}$ we find

$$I_M\omega_M + MmG^{\frac{2}{3}}(M+m)^{-\frac{1}{3}}\omega^{-\frac{1}{3}} + I_m\omega_m = \text{a constant} \quad .. \quad (2)$$

If m is small compared to M, we may put M for $M+m$ without altering appreciably the value of the second term. For instance, if we take $M = M_E$ and $m =$ a thousand billion tons (10^{21} gms.) the value of the term is not altered by one-millionth part through putting M_E for $M_E + m$. With this simplification the equation becomes

$$I_M\omega_M + m(GM)^{\frac{2}{3}}\omega^{-\frac{1}{3}} + I_m\omega_m = \text{a constant} \quad .. \quad .. \quad (2')$$

For a space-station circling the Earth the third term is negligible compared with the second, for $I_m = mk^2$ where k the radius of gyration of m cannot be more than half its longest diameter. The ratio of the third term to the second is therefore

$$k^2\omega_m\omega^{\frac{1}{3}}/(GM)^{\frac{2}{3}} = f.$$

But since r cannot be less than R_E it follows from equation (1') that ω cannot be more than $(GM_E)^{\frac{1}{2}}/R_E^{\frac{3}{2}}$ which is 0·001239 radians per second, so $\omega^{\frac{1}{3}}$ is less than 0·1074 units. It is most convenient to make $\omega = \omega_m$ or 0. In any case it cannot exceed 0·001239 radians/sec. without the inconvenience of of loose objects departing into space from its equator, unless its mean density greatly exceeds that of the Earth. (The permissible angular velocity is obviously proportional to the square root of the mean density of the rotating body.)

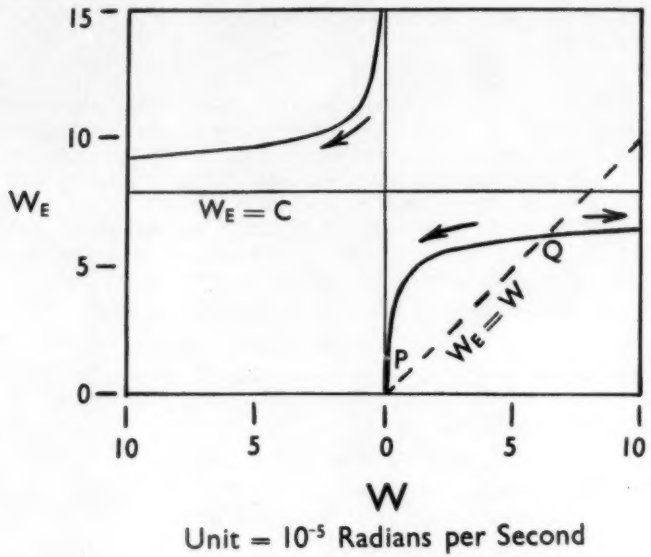
A space-station would hardly be more than 10 miles in diameter, making k less than 10^4, while $(GM) = 5{\cdot}412 \times 10^{13}$, so that

$$f \text{ is less than } 2{\cdot}5 + 10^{-6}.$$

Omitting the small term $I_m\omega_m$ and dividing by I_M equation (2') becomes

$$\omega_M = C - B\omega^{-\frac{1}{3}} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2'')$$

where $B = m(GM)^{\frac{2}{3}}/I_M$ is essentially positive, and C is the initial value of $\omega_M + B\omega^{-\frac{1}{3}}$.



In the diagram (Fig 1), the relationship of ω_E to ω has been plotted for the absurdly high value $m = 10^{25}$ gms. This value was chosen to give a clear figure. For a more reasonable value of m, the curve would merge in its asymptotes.

Taking the initial value of r as $7{\cdot}2\ 10^8$ cms. (nearly enough 500 miles above the Earth), the initial value of ω is found from equation (1') to be $1{\cdot}033\ 10^{-3}$ radians per second, and the values of $B = 0.000,000,666$ and $C = 0.000,079,510$ are easily obtained.

The graph of ω_E as a function of ω is rather like a hyperbola, with a horizontal asymptote at $\omega_E = C$, and a vertical one at $\omega = 0$. $d\omega_E/d\omega$ is everywhere positive, so that ω_E and ω increase together, r then diminishing, and conversely.

There is no tidal friction when $\omega_E = \omega$. The broken line PQ represents this condition, which can be fulfilled at only two points on the curve, P and Q. At P, ω is approximately $(B/C)^3$, and at Q about equal to $C - B(C - BC^{-\frac{1}{3}})^{-\frac{1}{3}}$. The values, which we shall call u and v come out to be $u = 0{\cdot}000,000,588$ (corresponding to a distance of 651,500 miles), and $v = 0{\cdot}000,062,750$ (corresponding to a distance of 28,950 miles from Earth's centre). At these two distances a satellite of mass 10^{25} gms, which had been planned to remain at 500 miles above the Earth's surface, could remain indefinitely, raising no tides that ebbed.

For points above and to the left of the broken line PQ, ω_E is greater than ω, tidal friction, therefore, acts as a brake on the Earth's rotation, ω_E diminishes and the changes ensuing are as indicated by the arrows in Fig. (1) to the left and

downwards. For points below and to the right of PQ, tidal friction accelerates the Earth's rotation, and, as the arrows indicate, the direction of change along the curve is to the right and upwards.

Tidal friction produces a couple retarding or accelerating the Earth's rotation. Since it is a gravitational effect, this couple must be proportional to m, the mass causing it. Since it depends on the variation of gravitational pull with distance, it must be proportional to r^{-3}. Since it is zero when $\omega = u$ or v, it must be proportional to a function of ω containing the factors $(\omega - u)$ $(\omega - v)$, and since it is finite and continuous and has no other zeros the function may be taken as $(\omega - u)$ $(\omega - v)$ multiplied by a finite, positive function $f(\omega)$. It is tempting to assume that the friction is proportional to $(\omega - \omega_E)$, as for *very* small values, it must be.

Then $f(\omega)\ (w - u)\ (\omega - v) = k\ (\omega - \omega_E)$

$$= k\ (\omega - C + B\omega^{-\frac{1}{2}})$$

and $f(\omega)$ takes the form

$$f(\omega) = \frac{k\{\omega^{\frac{1}{2}} + (u^{\frac{1}{2}} + v^{\frac{1}{2}})\omega^{\frac{1}{2}} + Bu^{-\frac{1}{2}}v^{-\frac{1}{2}}\}}{\omega^{\frac{1}{2}}(\omega^{\frac{1}{2}} + u^{\frac{1}{2}}\omega^{\frac{1}{2}} + u^{\frac{1}{2}})(\omega^{\frac{1}{2}} + v^{\frac{1}{2}}\omega^{\frac{1}{2}} + v^{\frac{1}{2}})}.$$

But the law of friction cannot be so simple, for we are dealing with a periodic disturbance of the oceans, and the disturbance and friction are a maximum when the period $2\pi/(\omega - \omega_E)$ coincides with a natural period of free oscillation of the oceans. For higher values of $(\omega - \omega_E)$ the friction diminishes with increase of $(\omega - \omega_E)$; and this is probably the actual case at present, for the seiches of the Sulu Sea and its adjacent channels appear to resonate with the chief tidal component, having about the quarter period for their free vibration. This gives about eight high tides in 25 hours, with considerable variations due to other tidal components, and variable interference by storms and earthquake.

If this small sea has so long a period (3 hours) for its free vibration, the natural period for the great oceans probably exceeds a day, and may be several days.

As we cannot be sure just how $f(\omega)$ varies, and have only one observation, the actual Earth-Moon system as it is, from which to deduce a value, we shall treat it as constant. There seems no reason why it should vary greatly in the small range from $\omega = 10^{-5}$ to $\omega = 10^{-3}$.

There will also be factors depending on the mass and geography of the Earth. Lumping all these together in one constant we obtain the third vital equation:

$$I_E d\omega_E/dt = Am(\omega - u)\ (\omega - v)/r^3 \quad .. \quad .. \quad .. \quad (3)$$

The value of A can be found by applying this equation to the cases of the Sun and Moon, the only bodies at present raising significant tides on Earth. Owing to its great mass, and the fact that for the Moon $\omega_m = \omega$, we cannot ignore the third term of equation (2) in the case of the Moon. So we have

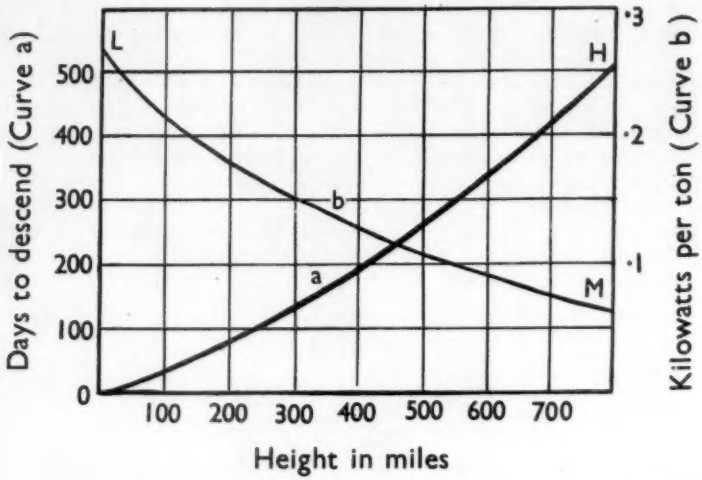
$$\omega_E + 0{\cdot}000\ 004\ 862\omega^{-\frac{1}{2}} + 0{\cdot}001\ 061\omega = 0{\cdot}000\ 423\ 77,$$

giving $u = 0{\cdot}000\ 001\ 53$ (therefore $r_P = 2{,}580{,}500$ kilometres) and

$v = 0{\cdot}000\ 354\ 65$ (therefore $r_Q = 14{,}743$ kilometres),

whence for the Moon

$$m(\omega - u)(\omega - v)/r^3 = -5{\cdot}022\ .10^{-6} \text{ gm./sec.}^2\text{cm.}^3$$



In the case of the Sun, the Earth's effect on the Sun is negligible, the curve of Fig. (1) lies close to its asymptotes, and with more than sufficient accuracy

$$u = 0$$
$$v = \omega_E$$

whence, for the sun

$$m(\omega - u)\ (\omega - v)/r^3 = -\ 8{\cdot}68 + 10^{-18}\ \text{gm./sec.}^2\text{cm.}^2$$

Adding the two couples we find

$$I_E d\omega_E/dt = -\ 5{\cdot}1097.10^{-16}.A.$$

The mean value of $d\omega_E/dt$ over the last 2,000 years is about $-\ 2{\cdot}235.10^{-22}$ radians per sec. per sec. (It is rather obscured by short-period variations of greater amount).

Hence $A = 3{\cdot}554.10^{38}$ cm.^{5}

For a light mass like a space-station the curve of Fig. (1) lies close to its asymptotes, making $u = 0$ and $v = 0{\cdot}000\ 072\ 921$ (i.e. ω_E).

Thus equation (3) reduces to

$$I_E d\omega_E/dt = Am\omega(\omega - 0{\cdot}000\ 072\ 921)/r^3 \quad .. \quad .. \quad .. \quad (3')$$

But omitting from (2) the minute term $I_m\omega_m$, and eliminating G by substitution from (1), we obtain the result

$$I_E\omega_E + mr^2\omega = \text{a constant} \quad \text{Since } M/(M + m) \text{ is } 0{\cdot}999\ 999.$$

$$\text{Therefore } I_E d\omega_E/dt = -\ md(r^2\omega)/dt = -\ m(GM_E)^{\frac{1}{2}} dr^{\frac{1}{2}}/dt$$
$$= -\ m(GM_E)^{\frac{1}{2}}(dr/dt)/2r^{\frac{1}{2}},$$

also from (1') $\omega = (GM_E)^{\frac{1}{2}}\ r^{-1\frac{1}{2}}$.

Substituting these values in (3'), and cancelling by $m(GM_E)^{\frac{1}{2}}$ we find

$$dr/dt = -2r^{\frac{1}{2}}A(G^{\frac{1}{2}}M_E^{\frac{1}{2}} - 0{\cdot}000\ 072\ 921\ r^{1\frac{1}{2}})/r^6 \quad .. \quad .. \quad (3'')$$

whence the time of descent from height R to Earth's surface is

$$t = +\int_{R_E}^{R} \frac{r^{5\frac{1}{2}}\ dr}{2A(G^{\frac{1}{2}}M_E^{\frac{1}{2}} - 0{\cdot}000\ 072\ 921\ r^{1\frac{1}{2}})} \quad .. \quad .. \quad (4)$$

Fig. (2) shows graphically the results given by integration of this equation, converted to familiar units. Tidal friction is able to bring down a satellite that starts 300 miles up in 136 days (just over 19 weeks), even from 600 miles it will take only 337 days (less than a year). *See* curve "a" running from 0 to H, ordinate scale on the left.

Since the satellite is moving with angular velocity ω against a couple of magnitude $Am\omega$ $(\omega - 0{\cdot}000\ 072\ 921)$, it is working at the rate of $Am\omega^2$ $(\omega - 0{\cdot}000\ 072\ 921)$ ergs per second against the drag of the seas. To maintain its height this steady loss of energy must be replaced at the same rate by rocket motors. The amount in kilowatts per ton of satellite is shown in Fig. (2), curve "b" from L to M, ordinate scale on the right. These results are only approximate, as A is not a true constant but may vary with ω. But they illustrate the order of magnitude of the effect.

(EDITORIAL NOTE:—

Mr. Logie's paper has been published with the object of stimulating research into this very important problem of the effect of tidal friction on an artificial satellite. His conclusion, that such a satellite would approach the Earth very rapidly, is rather unexpected. In view of this fact, other workers have been asked to comment upon his argument.

Dr. Davidson points out that a formula for the speed of approach v of a satellite is given by Sir Harold Jeffreys in his book, *The Earth*. Effectively, this is

$$\frac{v}{v_M} = \frac{\omega m}{\omega_M M}\left(\frac{R_M}{R}\right)^8,$$

where v_M is the velocity of the Moon's recession, ω, ω_M are the angular velocities of the satellite and the Moon respectively in their orbits, m, M are the respective masses of the satellite and Moon, R is the distance between the satellite and the Earth's centre and R_M is the distance between the Earth's centre and the Moon's centre. In the case of Mr. Logie's satellite, $m/M = 13{\cdot}5 \times 10^{-6}$, $\omega/\omega_M = 470$, $R_M/R = 52$ and hence $v/v_M = 15{\cdot}37 \times 10^8$. Since $v_M = 5$ ft. per century, $v = 14{\cdot}6$ miles per year. The artificial satellite would, according to this theory, take over 40 years to spiral inward to the Earth's surface. However, Dr. Davidson is not convinced that Jeffreys' investigations apply to Mr. Logie's problem.

Mr. Lawden states that any estimate of the effect of tidal friction upon an artificial satellite, must depend upon the tidal theory accepted by the computer. Such a tidal theory (e.g. that mentioned by Dr. Davidson) can, at present, only be checked by application to one particular case, viz. the Moon, and, he concurs with Dr. Davidson that it is doubtful whether any theory, which adequately describes the Moon's tidal effect, will also give satisfactory results when applied to circumstances differing greatly from those for which it was designed. However, he points out that Mr. Logie bases his argument upon no tidal theory. This suggests that his results are unlikely to be even approximately correct. In place of a tidal theory, the author asserts that the couple due to tidal friction must vanish when $\omega = u$ or v and consequently, its dependence upon ω may be expressed in the form $f(\omega)\ (\omega - u)\ (\omega - v)$. Only a complete tidal theory can suggest the correct form for $f(\omega)$. Lacking such a theory, the author takes this function to be a constant. By taking $f(\omega)$ to have other forms, almost any final result might have been obtained. Mr. Lawden therefore feels that no reliance can be placed upon Mr. Logie's final figure.)

NOTES AND NEWS

A Society Badge

A number of requests have been made by Members from time to time for a Society badge, and in response to this, the Council has now under consideration the question of making such a badge available.

Members are invited to send to the Council any suggestions for suitable designs, etc., which they would like to have considered.

Back Copies of Journals

A number of back copies of *Journals*, *Annual Reports*, etc., are available for sale to members.

Complete volumes for several previous years may be obtained at a special price of £1 5s. per volume, while many individual issues are also obtainable at 3s. 6d. each.

When ordering, please give alternatives wherever possible.

Orders and enquiries should be addressed to:—The Secretary, B.I.S., 12, Bessborough Gardens, London, S.W.1.

From the World's Press

The anniversary, 50 years of powered flight, brought a good deal of speculation on what the next half century might bring. Various prominent B.I.S. members appeared in odd places adding their contribution to the prophecies. But others were guessing too; Major Seversky, for example, was reported from New York as having prophesied travel to the Moon during the period under review. But he does not like rockets, he feels that they "will not prove practical, because the pilot cannot control the speed." In the *Farmer and Settler* of Sydney, he is reported as having favoured an atomic-powered 'plane which will start slowly and will climb through the Earth's atmosphere between 1,000 and 2,000 miles an hour. When clear of the atmosphere it will accelerate to a maximum of 130,000 miles an hour about half-way to the Moon and then gradually slow down for the rest of the journey. One wonders if Major Seversky has some "inside" information on atomic propulsion engines or has been merely misquoted.

* * * *

During the month of December, most of the newspapers carried reviews, often expanded into features, concerning the von Braun lunar expedition outlined in the *Colliers'* symposium and reprinted in book form by Sidgwick & Jackson. Strange to say, most of the reviewers had swallowed the story which, we believe, points to a moral. The general public seems now to accept as possible even the most unlikely interplanetary schemes providing they are backed by suitable names in the rocket or astronomical world. One of the main tasks of the interplanetary societies towards the close of this present century is likely to be to explain why the colonies have not been established on the Moon and Mars!

* * * * *

Project "Magnet" also attracted a fair amount of press comment during December. Canadian scientists are reported to have established a saucer sighting station ready for the close approach of Mars in 1956. Whether it is expected to establish communication with beautiful women from Mars as a complement to the god-like males from Venus, we are not sure, but if we can take Abbott and Costello's recent film as any indication, the 1956 opposition should be looked forward to with added interest. We are checking on our local deserts to see if we can locate a suitable trysting place for the Martian saucers. The *Hull Daily Mail* we are sure had made a slight error in the issue of December 1, when it was stated that the Project is being *packed* by the Canadian Government's Department of Transport. On the other hand, perhaps they were just hoping. As for ourselves, we dread the day when having given the usual answer to the inevitable question, we find on leaving the lecture hall, first a light tap on the shoulder and then, some days later, that conditions are not really so bad in the uranium mines on the Syrtis Major.

* * * *

And we proceed to that other Loch Ness Monster, the startling Russian rocket developments behind the Iron Curtain. There have been a number of reports during the last few months. In September *Japan News* reported George Sutton as having stated that Soviet scientists were planning to establish an artificial satellite. This information is supposed to have come from the interrogation of escaped technicians. There is probably about as much substance in this rumour as there is in that saying British and American scientists are planning to build a space-station. Some of them undoubtedly are, but whether or not a government will foot the bill is entirely another matter. In fact, a summary of intelligent postulations on Soviet rocket development prepared by Mr. Sutton for a recent issue of the *Journal of the A.R.S.* does not imply that any startling developments have been made. In this connection, the *Birmingham Post* of January 9, reports that the former Nazi Colonel, Baron Egbert von Frankenburg, has said that the Soviets have *further* (the italics are ours) developed a two-stage guided rocket for transatlantic purposes.

But *apropos* Russian development we were brought up with a definite jerk when our eyes scanned the headlines in the *Glasgow Sunday Mail* of November 29. The Soviets had an *underground* rocket! We had previously noticed that such machines were included in the morphology of transportation vehicles, but had rather thought that the appropriate morphological box came into the "impossible" category. Accordingly we made haste to read the story and absorb the details. What a disappointment! We found that some Russian had apparently just discovered Edgar Rice Burroughs' *Pellucider* and that the "prospector" had joined the other original inventions. The subterranean rocket turned out to be nothing more than a gigantic mole fitted with earth-screws.

* * * *

Still on a light vein, we were quite amazed by the ease with which space helmets can be constructed, according to *Woman's Day*, August, 1953. The reader is assured that the helmets have been "flight-tested by famous spacemen" and the coloured illustrations show headgear which would be a credit to any science-fiction technicolour epic. The materials sheets read like the old alchemy

books, for example, colander, corset stay, plastic cheesebox, spring, spool, acetate, rubber tubing, angle-iron, can, clothes line, felt, faucet spray, wire, bolts, and one paper clip. It seems inconceivable that the U.S. Navy should have spent hundreds of thousands of dollars on their suit which looks nowhere nearly so businesslike.

* * * *

The Scotsman still looks askance at extra-terrestrial aspirations. Following the British Association lecture by Sir Edward Appleton, the issue of September 4 expressed the hope that the many unknown factors in space travel would prove to be insuperable difficulties. This was based on the fear that the first use of a space-station must inevitably be to blast more effectively certain selected areas of the Earth's surface. The writer concerned has obviously been misled by the military space-station propaganda and should be assured forthwith that the artificial satellite will have little, if any, military value.

* * * *

On September 20, *Japan News* carried a report that the local astronautical society would start to register the names of people who wished to go to the Moon. They had to attend in person at 3 p.m. at the Chamber of Commerce. No indication of launching date was given, but we think it only fair to the registrants that they should have been advised to insert a suitable clause in their will so that the priority registration could be kept in the family.

* * * *

We liked the term "inhabited missile" applied by the U.S. Air Force Association to the F102 semi-robot interceptor aircraft. All the pilot has to do, it appears, is to operate certain switches at pre-determined times and finally to land the machine when it has been guided back to base. It seems that this is the nearest we have yet had to a prototype spaceship.

* * * *

A correspondent in the January issue of *Practical Mechanics* forces us to end this survey, by the sweeping statement "Interplanetary travel is impossible!" This epoch-making remark is consolidated by erudite arguments concerning movement in space and clinched with the newly discovered fact that "once

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outside the Earth's gravitational field a spaceship would be irresistably attracted to the Sun and would proceed in that direction at ever-increasing speed!" The last time we had this feeling of depression was when someone enlightened us to the "fact" that a rocket cannot thrust in a vacuum. Once again we are preparing to sell our collection of *B.I.S. Journals* and are wondering if we have spent 15 years of our life in vain.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950, issue of the *Journal*, and addenda have appeared in subsequent issues. The following is a further addendum to the list:—

Bol. Soc. Arg. Interplanet.	Bolletin de la Sociedad Argentina Interplanetaria.
Boll. Geod. Sci. Aff.	Bolletino di Geodesia e Scienze Affini.
Engrs. Dig.	Engineers' Digest.
Rev. Tech. Suisse (*S.T.Z.*).	Review Technique Suisse (S.T.Z.).

AERODYNAMICS

(See also abs. No. 185)

(136) **Heat transfer to bodies in a high-speed rarefied-gas stream.** J. R. STALDER, G. GOODWIN and M. O. CREAGOR. *N.A.C.A Rept., No.* 1093, 9 pp. (1952).

(137) **Aerodynamic forces on a cylinder for the free molecule flow of a non-uniform gas.** S. BELL and S. A. SCHAAF. *J. Amer. Rocket Soc.*, **23**, 314-317, 322 (*Sept.-Oct.*, 1953). It is shown that the shear stress and normal heat flux give rise to lift forces on the cylinder, while the tangential heat flux and the deviation of the normal stresses from the hydrostatic pressure give rise to additional drag forces. These are in general small except in regions of low flow velocity, where the forces arising from the heat flux terms become important (13 *refs.*).

AIRCRAFT

(138) **Some principal problems concerning the take-off of manned rockets.** E. BACHEM. *Weltraumfahrt*, **4**, 78-81 (*July*, 1953). (*In German.*) The designer reports on his experiences in testing the "Natter" rocket aircraft.

(139) **Douglas "Skyrocket" reaches Mach 2·01.** R. B. HOTZ. *Aviation Wk.*, **59**, 13-14 (*Nov.* 30, 1953). Details of record-breaking flight of Nov. 20, 1953.

(140) **Range comparison of rocket-powered aircraft.** R. W. ALLEN. *Aero. Dig.*, **67**, 30-32, 34, 36, 38, 42 (*Dec.*, 1953). Derives range formulae for constant thrust flight path and for constant thrust followed by power-off glide. The second method allows high-altitude and thus low-drag flight whilst maintaining a comparatively low speed and freedom from aerodynamic heating. It is shown that under certain conditions a rocket-powered aircraft can have a greater range than one with a conventional air-breathing power plant.

ASTRONAUTICS

(See also abs. No. 157)

(141) **The conquest of space.** M. G. MOULIN. *Rev. Tech. Suisse* (*S.T.Z.*) (52) (*Dec.* 27, 1951) (*In French*) (Long extracts in *Mém. Artill. Franc.*, **27**, 973-999 (1953)). General review of the problems of space-flight and possible solutions dealing with both chemical and atomic rockets.

(142) **Chemical problems of space-flight.** F. HECHT. *Weltraumfahrt*, **4**, 3-9 (*Jan.*, 1953). (*In German.*) A survey of chemical problems to be solved.

(143) **The evolution of the space vehicle.** H. GARTMANN. *Weltraumfahrt*, **4**, 36-42 (*April*, 1953). (*In German.*) A survey of actual developments and discussion of possibilities.

(144) **Abstracts of the papers presented at the 3rd Astronautical Congress.** T. TABANERA. *Bol. Soc. Arg. Interplanet.* (5), 4-21 (*July*, 1953) (*In Spanish*).

(145) **Take-off from satellite orbit.** H. S. TSIEN. *J. Amer. Rocket. Soc.*, **23**, 233-236 (*July-Aug.*, 1953). Characteristic velocity for the take-off of a space-ship from the satellite orbit is computed for radial thrust and circumferential thrust conditions. The latter is the more efficient method.

(146) **A consideration of space-ship shape.** R. C. ABEL. *Aeronautics*, **29**, 164, 167-168 (*Sept.*, 1953). A space-ship can be likened to a building or other mass supported by forces at one end and its structure should therefore be tower-like.

(147) **Astronautics.** *Neue Zürcher Zeitung*, sheet 6 (*Sept.* 2, 1953) (*In German*). Abstracts of papers delivered at the Fourth International Congress held in Zurich, Aug., 1953.

(148) **Astronautics.** J. ACKERET. *Neue Zürcher Zeitung*, sheet 5 (*Sept.* 2, 1953) (*In German*). General review with emphasis on artificial satellites.

(149) **The 4th International Congress on Astronautics.** H. GARTMANN. *Weltraumfahrt*, **4**, 122-125 (*Oct.*, 1953) (*In German*). Review of the proceedings.

(150) **Legal problems of space-flight.** W. HEINRICH. *Weltraumfahrt*, **4**, 116-121 (*Oct.*, 1953) (*In German*).

(151) **On the importance of modern computers for space research.** B. THÜRING. *Weltraumfahrt*, **4**, 110-115 (*Oct.*, 1953) (*In German*). Description of computing machines and examples of application to space-flight problems.

(152) **Fourth International Astronautical Congress.** P. GALLINA. *Boll. Geod. Sci. Aff.*, **12**, 534-536 (*Oct.-Nov.-Dec.*, 1953) (*In Italian*). Review of proceedings.

(153) **Space experts outline targets.** D. A. ANDERTON. *Aviation Wk.*, **60**, 34, 36, 38, 40, 41 (*Jan.* 18, 1954). Review of A.R.S. Space-Flight Symposium.

ASTRONOMY

(154) **The Moon.** **2** (2) (1953). Various short papers and notes concerning observation of the Moon.

(155) **Life on Mars.** H. STRUGHOLD. *Weltraumfahrt*, **4**, 24-26 (*Jan.*, 1953) (*In German*). Estimate of possibilities for life on Mars, taking into consideration the environmental conditions.

(156) **The Mars-Moon Phobos—a dissolving Moon?** W. SCHAUB. *Weltraumfahrt*, **4**, 65-67 (*July*, 1953 (*In German*). Outline of a new hypothesis.

(157) **Navigational calculations in space-flight.** Pt. II. H. KETCHUM. *J. Space Flight*, **5** (7), 1-5 (*Sept.*, 1953). Deals with uncertainties in planetary orbital velocities and gravitational fields and the gravitational field of the Sun.

(158) **The determination of the orbit by the vector of the velocity and the influence of its variation on the orbital elements.** K. SCHÜTTE. *Weltraumfahrt*, **4**, 98-107 (*Oct.*, 1953), and **5**, 13-20 (*Jan.*, 1954) (*In German*). A new method to determine the orbital elements by the velocity vector. May be applied to the determination of the orbits of rockets and stars.

ATMOSPHERE

(See also abs. No. 181)

(159) **Man-made meteors to spy on space.** E. HUTCHINGS and O. J. EGGEN. *Pop. Sci. Mon.*, **163**, 93-97, 240 (*July*, 1953). Small pieces of metal can be made to reach very high speeds by means of shaped charges and it is hoped to reach escape velocity by sending them up in rockets and firing. The only experiment to date failed.

(160) **Rockets and the upper atmosphere.** H. E. NEWELL. *Sci. Mon.*, **78**, 30-36. (*Jan.*, 1954). Deals with investigations of the upper atmosphere in which the rocket has played an essential part such as ozone distribution, density, ion density, solar X-rays, current sheets, high altitude winds and cosmic rays and discusses problems still to be solved (17 *refs.*).

(161) **Rocket-borne servo tracks the Sun.** D. S. STACEY, G. A. STITH, R. A. NIDLEY and W. B. PIETENPOL. *Electronics*, **27**, 149-151 (*Jan.*, 1954). A spectrograph mounted in the nose-cone of an "Aerobee" rocket was continually aimed at the Sun by a biaxial servo system. Deviation was detected by a balanced phototube system with coarse and fine control. Selection of components is described. First firing was a failure, but on second an accuracy of 15 minutes of arc was obtained.

(162) **"Aerobee" rocket probes upper-air riddles.** W. J. COUGHLIN. *Aviation Wk.*, **60**, 30-32 (*Feb.* 1, 1954). Review of research made with "Aerobee."

BIOLOGY AND MEDICINE

(See also abs. No. 155)

(163) **The psychophysiology of acceleration effects.** S. J. GERATHEWOHL. *Weltraumfahrt*, **4** 15-19 (*Jan.*, 1953) (*In German*). Concerning the adaptability of pilots to acceleration.

(164) **Physics and psychophysics of weightlessness.** H. HABER and S. GERATHEWOHL. *Weltraumfahrt*, **4**, 44-50 (*April*, 1953) (*In German*). Analysis of supposed psychophysical phenomena of weightlessness.

CHEMISTRY

(See also abs. No. 142, 204 and 205)

(165) **Explosive properties of nitromethane.** L. MÉDARD. *Mém. Poudr.*, **33**, 125-135 (1951) (*In French*). Nitromethane is remarkably insensitive to shock, but when it does detonate it is a very powerful explosive.

(166) **A field analysis for white fuming and anhydrous nitric acid.** J. D. CLARK. *Naval Air Rocket Test Station Rept. No.* 23, 22 pp. (*Sept.*, 1952).

(167) **Determination of excessive sludge formation in mixed acid storage drums.** A. E. LENEHAN. *Naval Air Rocket Test Station Rept. No.* 29, 8 pp. (*Feb.*, 1953).

(168) **Stability of pure hydrogen peroxide.** E. M. ROTH and E. S. SHANLEY. *Industr. Engng. Chem.*, **45**, 2343-2349 (*Oct.*, 1953). Preparation and stability of very pure (99 + per cent.) hydrogend eroxide. Compares favourably with stabilized samples. Investigation of effect of stabilizers, temperature and container walls on stability.

MISCELLANEOUS

(169) **Five years of the Gesellschaft für Weltraumforschung.** H. GARTMANN. *Weltraumfahrt*, **4**, 20-21 (*Jan.*, 1953) (*In German*). A report on the activities of the GfW during its first five years of existence.

PHYSICS

(See also abs. No. 199)

(170) **Heat transfer measurements for white fuming nitric acid.** E. ASHLEY. *Bell Aircraft Corp. Rocket Sect. Rept. No.* 56-982-016, 43 pp. (*Feb.*, 1953).

(171) **Maximum evaporation rates for non-isothermal droplets.** F. W. HARTWIG. *J. Amer. Rocket Soc.*, **23**, 242-243 (*July-Aug.*, 1953). Calculations have been made to determine the rate of evaporation of a liquid droplet surrounded by hot gases. Results were in satisfactory agreement with the known data for evaporation of isothermal droplets, thus justifying calculations for isothermal droplets as a reasonable first assumption.

(172) **Mechanism of combustion of gunpowders and explosives.** C. H. JOHANSSON. *Tekn. Tidskr.*, **23**, 695-698 (*Sept.* 22, 1953) (*In Swedish*). (Long extract in *Engrs'. Dig.* **15**, 12-14, 36 (*Jan.*, 1954)). Reviews the theories of Belaev, Corner and Sänger and shows that experimental rates of combustion for a gelatine dynamite fit Sänger's equation.

(173) **Remarks on the luminescence hypothesis for flames.** E. SÄNGER. *Weltraumfahrt*, **5**, 4-9 (*Jan.*, 1954) (*In German*).

PROJECTILES

(174) **On the solution of the differential equations of missile flight.** C. CASCI. *Studia Ghisleriana*, **1** (4) (1952) (*In Italian*). The differential equations are not definitely integrable. By dividing the trajectory into convenient portions and using mean values of the mass ratio and motor performance expressions are obtained for the velocity and distance traversed in terms of Bessel, trigonometric and logarithmic functions. The final section considers vertical flight ignoring air resistance.

(175) **The influence of engine data on the flight performance of rockets.** H. H. KÖLLE. *Weltraumfahrt*, **4**, 68-75 (*July*, 1953) (*In German*).

(176) **Woomera breaks the news barrier.** *Interavia*, **8**, 508-509 (*Sept.*, 1953). Description of the Woomera testing range with details of the type of country, installations and some of the work in progress.

(177) **The evaluation of competing rocket power plant components for two-stage long-range vehicles.** A. L. FELDMAN. *J. Amer. Rocket Soc.*, **23**, 297-300 (*Sept.-Oct.*, 1953). The criterion proposed is the minimum net cost of a missile to perform a certain function. Characteristics of a hypothetical vehicle are presented and curves are given which show the compromise allowable between weight and efficiency for any power plant component or between competing power plants. Several power plant arrangements are analysed for this example.

(178) **Russia's guided missiles.** K. W. GATLAND. *R.A.F. Flying Rev.*, **9**, 11-14 (*Oct.*, 1953). States that Russia has developed the A.4 and "Wasserfall" and produced a two-step rocket with a range of 3,000 km.

(179) **British guided missiles.** *Interavia*, **8**, 635 (*Nov.*, 1953). Seven officially released pictures of British guided weapons. Lists some firms working on guided weapons and stresses absence of information.

(180) **Rocket development in France.** *Interavia*, **8**, 636-637 (*Nov.*, 1953). Information on "Matra M.04" and "Veronique."

(181) **The "Aerobee" research rocket.** A. L. ANTONIO. *Interavia*, **8**, 631 (*Nov.*, 1953). Gives overall dimensions, performance details, method of launching and describes some of its applications to upper atmosphere sounding.

(182) **Within the shadow of Russia's guided missiles.** K. W. GATLAND. *Interavia*, **8**, 632-634 (*Nov.*, 1953). Collects information to show that the Russians must by now have advanced considerably along the lines laid down by the Germans. Stresses that Russian guided weapon work is underestimated.

(183) **Launching system for self-propelled missiles**. W. PILZ. *Interavia*, **8**, 663-664 (*Nov.*, 1953). Enumerates the disadvantages of launcher-rails and jet vanes for stabilization in the first moments of flight and advocates the use of widely separated control cables paid out at identical speeds from drums on the ground.

(184) **Production study of Martin "Viking."** *Aviation Wk.*, **59**, 55 (*Nov.* 9, 1953). Analysis shows how "Viking" could be adapted for weapon use and high production rate. Lists materials and methods of construction of the 10 constructed and the four projected with comments on possible future changes.

(185) **Guided missiles at Wallops.** J. A. SHORTAL. *Aero Dig.*, **68**, 38, 40, 42 (*Jan.*, 1954). Account of aerodynamic research techniques using rocket-propelled models as used by NACA.

RADIO AND ELECTRONICS

(See also abs. No. 151)

(186) **Electronics in space (guided missiles)**. C. DE VORE. *Signal*, **7**, 27-29 (*Nov.-Dec.*, 1952).

(187) **Telemetering requirements for upper-air rocket research**. M. O'DAY. *Convention Record Inst. Radio Engrs.*, 48-51 (1953). General review and description of some American installations.

(188) **Principle electronic scheme for automatic pilot of long-range rocket.** J. M. J. KOOY. *Ingenieur* (20) (1953). Proposed system for ballistic missile using gyroscopes for sensing and rudders for control.

(189) **Transistors in telemetry**. F. M. RIDDLE. *Electronics*, **27**, 178-180 (*Jan.* 1954). Equipment for f.m./f.m. telemetering is light, compact and efficient. For short-term use transistor instability is not important.

ROCKET MOTORS

(190) **Rocket-motor performance computer**. R. A. BUCHANAN. *Calif. Inst. Tech, Jet Prop. Lab. Memo., No.* 20-77, 18 pp. (*Oct.*, 1952).

(191) **Cold extrusion saves time and material in making rocket elements.** J. GESCHELIN. *Autom. Ind.*, **108**, 62-65 (*Jan.*, 1953).

(192) **On the determination of the optimum combustion chamber pressure of rocket motors.** H. H. KÖLLE. *Weltraumfahrt*, **4**, 9-15 (*Jan.*, 1953) (*In German*). Effects of combustion chamber pressure on engine weight and take-off mass.

(193) **Device for feeding liquid combustion agents to a combustion chamber used in propulsion apparatus.** R. H. GODDARD. *U.S Pat. No.* 2,630,674 (*March* 10, 1953). Annular injector design.

(194) **Combustion chamber with target recess for use in rocket apparatus.** R. H. GODDARD. *U.S. Pat. No.* 2,633,706 (*April* 7, 1953). Annular injector spraying back into target recess.

(195) **Compact container arrangement for propellant feeding means of rockets.** F. B. HALFORD and A. V. CLEAVER. *U.S. Pat. No.* 2,634,577 (*April* 14, 1953). Layout of propellant tanks, compressed-air bottles and chamber for pressure-fed motor.

(196) **High-pressure pumps.** U. M. BARSKE. *Engineer*, **195**, 550-553 (*April* 17, 1953). Hollow and open impeller centrifugal pumps are described. Both types are most suitable for high-speed operation and a high pressure rise can be obtained in one stage and will allow a wide variation in flow rate at a constant speed.

(197) **Process of ignition for rockets and the like.** J. T. TSCHINKEL. *U.S. Pat. No.* 2,637,161 (*May* 5, 1953). Third fluid system for igniting liquid propellants.

(198) **On the testing of small rockets with liquid propellants.** H. STOELZEL. *Weltraumfahrt*, **4**, 82-85 (*July*, 1953) (*In German*).

(199) **A modified sodium-line reversal technique for the measurement of combustion temperatures in rocket engines.** M. F. HEIDMANN and R. J. PRIEM. *J. Amer. Rocket Soc.*, **23**, 248-253 (*July-Aug.*, 1953). The technique was used to measure temperature at several stations within an open tube rocket combustor using liquid oxygen and alcohol as propellants. The results show that the technique may be successfully applied to the study of combustion reaction time in rocket motors (12 *refs.*).

(200) **Theory of steady flow with mass addition applied to solid propellant rocket motors.** E. W. PRICE. *J. Amer. Rocket Soc.*, **23**, 237-241 (*July-Aug.*, 1953). Steady flow of a perfect gas in a straight duct is discussed and the problem is then combined with the discharge characteristics of sonic nozzles assuming gas produced by a solid propellant. Flow field shown to depend on two dimensionless geometrical variables (12 *refs.*).

(201) **High-frequency combustion instability in rocket motor with concentrated combustion.** L. CROCCO and S.-I. CHENG. *J. Amer. Rocket Soc.*, **23**, 301-313, 322 (*Sept.-Oct.*, 1953). Crocco's earlier work is extended to deal with arbitrary location of a concentrated combustion front. The frequencies excited by the interaction between the combustion process and the pressure oscillations are close to the natural frequencies of the combustion system. Rockets with very short nozzles are more unstable than similar rockets with long nozzles.

(202) **Flow through nozzles in rocket motors.** R. KLING and R. LEBOEUF. *Rech. Aéronaut.*, (35), 35-41 (*Sept.-Oct.*, 1953) (*In French*). (Long extract in *Engrs. Dig.*, **14**, 460-463 (*Dec.*, 1953)). Experimental investigation of the flow of liquids through plain injection holes. Parameters investigated were injection pressure, orifice shape, liquid temperature, back-pressure and type of liquid.

(203) **Problems of rocket propulsion at the Fourth International Astronautical Congress.** *Interavia*, **8**, 641 (*Nov.*, 1953). Report on the papers dealing with rocket engineering.

ROCKET PROPELLANTS

(See also abs. Nos. 166 and 167)

(204) **Analytical procedures for rocket propellants, VI. White fuming nitric acid.** J. D. CLARK and H. G. STREIM. *Naval Air Rocket Test Station Rept. No.* 20, 42 pp. (*June*, 1952).

(205) **Analytical procedures for rocket propellants, VII. Mixed acid.** J. D. CLARK. *Naval Air Rocket Test Station Rept. No.* 24, 18 pp. (*Sept.*, 1952).

(206) **A comparison of propellants and working fluids for rocket propulsion.** K. A. EHRICKE. *J. Amer. Rocket Soc.*, **23**, 287-296, 300 (*Sept.-Oct.*, 1953). A series of chemical propellants and atomic working fluids are compared with respect to vehicle performance and design parameters. The changing influence of density and specific impulse with increasing performance is discussed. Ranges for favourable application of different fluids are indicated and their respective limits of applicability shown for ascent in a gravity field as well as for space flight.

(207) **An analytical consideration of rocket propellants.** C. N. S. SCULLY. *Pacif. Rocket Soc. Bull.*, **6** (9), C1-C3 (*Sept.* 10, 1953). Elementary considerations of desirable properties from a performance point of view.

ROCKET PROPULSION

(208) **General theory of step-rockets.** H. KRAUSE. *Weltraumfahrt*, **4**, 52-59 (*April*, 1953) (*In German*). Nondimensional relationships for the calculation of step-rockets.

(209) **Nuclear energy and rocket propulsion in aeronautics.** A. V. CLEAVER. *Atomic Scientists' News*, **2**, 293-299 (*May*, 1953). (Also in *Aeroplane*, **84**, 736-738 (*June 5*, 1953)). Review of methods of application of nuclear energy for air-breathing engines and for rockets.

(210) **A chapter in rocket history.** W. H. J. RIEDEL. *Weltraumfahrt*, **4**, 86-90 (*July*, 1953) (*In German*). Report on some of the rocket-car tests of the German rocket pioneer, Max Valier.

(211) **America's growing rocket industry.** A. L. ANTONIO. *Interavia*, **8**, 630-631 (*Nov.*, 1953). Short description of a typical firm (Aerojet) engaged in rocket-missile work, its range of personnel and interests.

(212) **A few comments on rocketry.** T. VON KÁRMÁN. *Interavia*, **8**, 628-629 (*Nov.*, 1953). A brief outline of the history and some of the problems of rocket motors and guided weapons.

REVIEWS

A Rocket Drive for Long Range Bombers

(By Drs. Eugen Sänger and Irene Bredt. Deutsche Luftfahrtforschung UM 3538, Ainring, Bavaria, 1944. Translated by M. Hamermesh, U.S.N. Now published as photolithograph reproduction, 175 pp., diags., photos., etc., at $3·95, by Dr. Robert Cornog, 990, Cheltenham Road, Santa Barbara, California, U.S.A. November, 1952.)

During the recent war, the man who became the first President of the I.A.F., and the charming lady who is now his wife, worked in various German research establishments on military applications of rocket and ramjet propulsion, high-speed aerodynamics, and other advanced physical phenomena. We now know that, in common with many other scientists on both sides of the struggle, they would have preferred to devote their considerable talents to more peaceful ends, and (especially in the case of Sänger and Bredt) not least to astronautics. It is some consolation to those of us who share their intense interest in this latter subject that much of their work made a great, even if indirect, contribution to its progress.

The item of greatest interest in this connection is the subject of this present review. First published in Germany as a secret report with a very limited and select circulation, in the concluding months of the war, it immediately became the object of very careful study and attention by all the Allied Intelligence teams which were sent to Germany in 1945 to report on enemy achievements in science and technology. There is some evidence that the Russian investigators were perhaps the most interested of all (*see* review of Tokaev's *Stalin Means War*, in *J.B.I.S.* for September, 1951, pp. 230-231).

The work in question can only be described as a truly monumental and exhaustive study of the possibilities of a giant rocket-propelled aircraft, capable of circumnavigating the Earth non-stop. It would have employed a very radical flight technique, climbing beyond the atmosphere to fall back into its denser layers and then follow an undulatory trajectory, rather similar to the path of a

stone skimmed across the surface of a pond. The initial launch, at supersonic speed, would have taken place from a ground carriage, itself rocket-propelled, along a 3 km. length of track. The weight at take-off would have been 100 tons; the crew and payload weights would nevertheless have been only of the same modest order as for a conventional light bomber, such as the British "Mosquito." Even though flight was envisaged at many thousands of kilometres per hour, the final landing speed would have been about the same as for contemporary fighters, due to the greatly-reduced weight of the aircraft after consumption of all its rocket propellants.

The extremely thorough nature of the study can be gauged even from a brief review of its contents: the subjects discussed include rocket motor thermodynamics and high-energy propellants, aerodynamic phenomena (including heating) at very high Mach Nos. and in very rarified atmospheres, sliding friction at great velocities (in connection with the launching device), practical engineering considerations of the construction of big rocket motors and their testing, storage of liquefied gases, and even the theory of bombing accuracy from great altitudes and speeds and acceleration effects on the human body. This list is by no means exhaustive, and many of the comments and contributions made by the authors were of a highly original nature.

Rocket engineers in particular, but indeed everyone with a detailed and technical interest in astronautics, should feel grateful to the U.S. Naval Bureau of Aeronautics and to Dr. Cornog for at last making this important work available to the public. For some reason, the official English translations were classified for a long time, even after it was shown that copies of the original report were in Russian and French hands, as well as British and American. Any scientist or engineer working in the actual fields of rocket motors or guided weapons, or high-speed flight generally, is strongly recommended to obtain a copy. If nothing else, he should find its perusal extremely stimulating, and probably rewarding in an even more detailed sense, by reason of the many new ideas it may give him.

It is perhaps only fair to conclude by explaining that there is little doubt that Sänger and Bredt regarded their work only as a preliminary project study of something which was a long-term practical possibility, provided that certain research (which they carefully outlined) was undertaken beforehand. They never imagined that their project could immediately have been designed in detail, constructed, and flown, within the space of a few short years. Tokaev leads us to believe that the gentlemen of the Politbureau never understood this elementary fact of technical life, and present readers should not repeat their mistake, for we are still (in 1954) some way removed from being in a position to build a craft of such advanced conception. Some of the authors' assumptions still appear on the optimistic side.

It might well be argued that, with the advent of long-range unpiloted guided missiles (of the A4 or A9/A10 family), we shall never want to build bombers of such a type, even when we are technically capable of so doing. Any civil version of this kind of aircraft also seems rather unlikely, both in regard to its value (as compared with future jet airliners of more conventional character) and the economics of its operation. However, the problems studied by Drs. Sänger and

Bredt, and the results they obtained, will find other important applications in the missile and aircraft fields. Especially, their pioneering work will come to be fully appreciated when the first Earth satellite rockets, with wings for return landing, are built and piloted by their human crews to and from orbits beyond the atmosphere. A. V. CLEAVER.

Flight into Space

(By Jonathan Norton Leonard. Sidgwick & Jackson, Ltd., London, 1953. 245 pp. 12s. 6d.)

The sub-title of this book is "Facts, Fancies and Philosophy" and although the facts are presented in a highly readable manner, the author's style is rather overpoweringly American.

Some of the fancies undoubtedly compel thought, and bring a new slant to many of the current ideas in astronautics, though it is likely that some of the theories advanced are not likely to gain a large measure of acceptance, at least on this side of the Atlantic.

The author's philosophy is sober and realistic, for Mr. Leonard has no axe to grind, and is careful to mention the demerits, as well as the merits of the ideas which he presents.

This book is written for the layman; figures are kept to a minimum and formulae are entirely absent.

The absence of illustrations is rather a detriment, but Mr. Leonard's graphic style goes a long way towards filling the gap.

The book contains a good, if critical, examination of Dr. W. von Braun's artificial satellite proposal, which is well worth reading. Also of interest are the chapters on "Missile Neurophysiology"—a study of electronic computers used for rocketry, and "Into the Black Yonder" which contains some ideas of intergalactic travel for the science fiction fans.

The book is a most interesting general account of space-flight, and is neither over-optimistic nor unduly pessimistic.

It will not make the cautious more sceptical, nor disgust the enthusiast, but is hardly a book for the expert, who will find many points covered in only a cursory manner. M. S. WRIGHT.

Flying Saucers

(By Donald H. Menzel. Published by Putnam & Co., Ltd. London, 1953. 319 pp. Price 21s.).

Parts of this book are good, parts are not. Unfortunately the questionable sections are just those which illustrate the main thesis of the book. This, the author makes clear in his preface, is a claim that all flying saucers which have not yet been explained away are caused by the "rags and tags of meteorological optics: mirages, reflections in mist, refractions and reflections by ice crystals." The author is a Professor of Astrophysics, but whatever the reader is intended to think, this is not the same as being a meteorologist, as the book soon shows.

As early as page 9, we read that "highly turbulent . . . rapidly shifting, tilting clouds of snow would reflect the sun like a mirror." But one look at a snowflake is enough to show that a turbulent mass of them could not possibly

give a reflection like that seen in a mirror, even if it were tilted—whatever that may mean. Then, immediately below these words, there is a photograph described as "storm clouds developing from air rising over a hogback," showing a storm cloud which must be at least ten times as far off as the hogback in the foreground, as should be obvious to any experienced cloud-watcher.

As to "mock suns," which receive so much attention from the author, they can only be produced in air which is so far from being turbulent that the ice crystals all take up the same orientation. A mock sun is most commonly seen 22 degrees to right or left of the sun at the same altitude above the horizon. It can be either a short strip of impure rainbow colours, or a bright patch of white light; thus it need not be coloured, in spite of what the author says on p. 190. But whether coloured or not, its brightness fades gradually into the surroundings, so it is hard to see how any mock sun could be mistaken for a solid object. Nevertheless it does seem to have been so mistaken on January 7, 1948, at Fort Knox, Kentucky, when Captain T. F. Mantell chased an alleged flying saucer to 20,000 ft. and then passed out, crashed and was killed.

Observers on the ground saw an object like "an ice-cream cone topped with red." (p. 20). Presuming it was lying on its side, this corresponds well enough to the coloured-strip type of mock sun, which is widest at the red end and tapers towards the blue, except for the aforementioned lack of a sharp outline. Furthermore, Captain Mantell reported by radio, at 3.15 p.m., that its bearing was 210 deg., which would be about the position of a mock sun to the left of the true sun, allowing certain adjustments for time and trigonometry. Yet the author, having almost proved his point, must needs suggest (p. 198) that Captain Mantell saw a "sub-sun" (a rarer sort of mock sun directly below the real sun), mistook it for the sun, and then imagined the real sun, "partially dimmed by crystals of frost," to be a flying saucer. All this despite the fact that the bearing of the object was much nearer the mock sun than the true sun, even without the aforesaid adjustments.

Take another case: Lieut. G. F. Gorman, coming down to land in the dark at Fargo, North Dakota, noticed a light which he chased (p. 16). After a sort of dog-fight with it, he saw the light come straight at him, so he dived and it passed over his canopy. Dr. Menzel states dogmatically: "the object was only light reflected from a distant source by a whirlpool of air over one wing of the 'plane" (p. 19). What is a whirlpool of air? How can it reflect light? And even if it could reflect as well as refract, why should the pilot see the light in an entirely different direction from the supposed position of the whirlpool?

Then there is the alleged "flying saucer" which passed by two airline pilots over Alabama (p. 14), and pulled up with a burst of flame from the rear which rocked the aeroplane, a DC-3. The author, of course, knows all the answers: "a layer of cold air sandwiched between two layers of hot air," making an "atmospheric lens" (p. 216). But a layer of cold air immediately above hot cannot persist in the upper atmosphere; the two layers must immediately change places, which they do by means of a pattern of up and down currents. These vertical currents, we are told dogmatically, were mistaken for the blast from the "saucer."

But thin layers of cold air do not suddenly appear *de novo* in the upper air, except perhaps at the upper surface of a high cloud sheet which is radiating its warmth out into space, and there is no mention of cloud on this occasion.

Again, the author tries to explain a lens, allegedly caused by the passage of a meteorological balloon, by postulating a cold layer pushing a perfect and persisting hemispherical bulge into a warm layer beneath. Three whole pages in an appendix are given to a mathematical investigation of this impossible situation, whereas it could have been made quite reasonably plausible by putting the cold layer beneath instead of on top, with the convex "lens" facing upwards to produce a saucer-shaped image of the balloon.

It is nevertheless possible for a cooler layer to overlie a warmer layer within a few feet, or even inches, of the ground when it is being warmed by the sun; such a situation can persist for most of the day, because the viscosity of the air does not allow a quick interchange of the hot and cold layers. Mirages are thus facilitated, and can produce saucer-shaped illusions. Here, at last, the author is on safe ground; and, if he were not so obsessed with aerial sandwiches, he could have explained under what circumstances similar mirages can be produced at higher levels where warm air overlies cold—a common enough occurrence known technically as an "inversion."

Summing up, the reviewer's conclusion is that a certain proportion of alleged "saucers," not otherwise explainable, can be explained by meteorological optics, particularly since many more pilots than previously have been flying high among the ice-crystal clouds and must be seeing mock suns and similar phenomena more often, and at closer range, than earthbound people see them. But the remainder are not to be explained away by a lot of loose verbiage which means little and proves less.

There is, nevertheless, much of interest in the book. apart from its main thesis. A diagram on p. 58 shows that there have been over a hundred unexplained "saucer" sightings each year since 1947, and in the first half of 1952 alone the number jumped to 318. The "Little Men from Venus" hoax at Denver is described more truthfully than in the book by Frank Scully, whom Dr. Menzel accuses of omitting "certain highly significant details." And there are some amusing examples of popular stupidity on the occasion of Orson Welles's broadcast of "The War of the Worlds"; e.g. a Princeton geology professor actually set out to get a sample of the alleged meteorite.

An interesting collection of strange sights in the sky, from various historical sources, is only marred by the author's persistence in calling them "saucers," whatever their shape and despite the fact that nobody called them that at the time. And a phenomenon seen in Norfolk (p. 108), which was obviously a miniature tornado—the land equivalent of a waterspout—has to be explained away by him as a solar halo.

There are some sensible remarks about the unlikelihood of "flying saucers" being spaceships from other planets, and an interesting suggestion that the Martian vegetation may have evolved from seaweed-like plants in the "ancient sea beds." The book ends with a specimen form for reporting "saucer" observations to the Air Intelligence Centre at Wright Field, Dayton, Ohio.

DR. A. E. SLATER.

Tables for Rocket and Comet Orbits

(By Samuel Herrick. Published by U.S. Department of Commerce National Bureau of Standards, 1953. 100 pp.. ($1·75.)

Employing these tables, a complete numerical solution to the problem of the rectilinear motion of two gravitating bodies may be obtained by the simple processes of interpolation or inverse interpolation. There are three cases: (i) when the combined energy H of the two bodies is insufficient to permit their ultimate complete separation, (ii) when H is large enough to permit complete separation, and (iii) the intermediate case. These three cases correspond to the elliptic, hyperbolic, and parabolic motions respectively, when the motion is two-dimensional. In the first case, a parameter E is introduced and tables are provided of $\sin E$, $(1 - \cos E)$ and E, tabulated against an argument $(E - \sin E)$. If T is the instant of zero separation and t is any other instant, $(t - T)$ is proportional to $(E - \sin E)$. Knowing the instant at which the relative velocity and separation of the bodies is required, the corresponding value of the argument $(E - \sin E)$ is easily calculated and reference to the tables then provides the appropriate values of $\sin E$ and $(1 - \cos E)$. From these quantities, the relative velocity and separation are immediately calculable. In the second case, $\sinh F$, $(\cosh F - 1)$, and F are tabulated against $(\sinh F - F)$ as argument and perform a similar function. In the parabolic case, D and $\frac{1}{2}D^2$ are tabulated against $\frac{1}{6}D^3$.

In the elliptic case, only the range $0 \leqslant E \leqslant \pi$ need be covered and the tables are complete. In the hyperbolic case, the range covered is $0 \leqslant F \leqslant 6{\cdot}4181$. In the parabolic case, the tables may be entered for any value of D, for, like any power tables, they are largely independent of the position of the decimal point. Advantage is taken of the fact that, for small values of the parameters E, F, D, the three cases are indistinguishable and hence only one table need be provided and this, being largely independent of the position of the decimal point, provides an accuracy of at least eight significant figures no matter how small the parameter. Nine or ten significant figures are available over the main body of the tables. First and corrected second differences are provided where these are necessary for accurate interpolation and it is assumed that this process is carried out using Everett's formula. In this connection, a table of Everett coefficients is provided at the end of the work.

The tables are also suitable for the computation of nearly parabolic or "cometary" orbits and a full explanation (with examples) of their use for this purpose is given in the Introduction. This section also describes the manner in which the tables were computed.

Considerable ingenuity has been exercised by the author and his co-workers in compressing a great quantity of numerical information into a small space, without sacrificing simplicity of layout. It seems unlikely to the reviewer, however, that the result will find much application in the field of rocket orbits, for, although the first phase of a rocket's motion, after leaving its launcher, is likely to be rectilinear, for accurate computation the air resistance force will have to be taken into account. Once out of the atmosphere, a more economical, two-dimensional trajectory will be followed. As a means of calculating comet orbits, however, the tables should be popular. D. F. LAWDEN.

CORRESPONDENCE

Lunar Accommodation——I

SIR,

I would like to outline an idea for another type of construction of "lunar buildings."

A sheet of lightweight flexible material would be stretched across a small crater or cleft, the space beneath then being filled with gas, the pressure of which would be adjusted to balance the weight of the sheeting—so that slight tensile forces applied to the sheeting would cause it to assume a flat horizontal shape. A quantity of fine sand or dust would then be spread in a shallow even layer over the sheeting whilst the internal gas pressure would be adjusted so that the "roof" remained flat. This fine dust layer would be increased gradually to (say) a foot. Then the surface would be covered, in stages, with dust and rubble, whilst the internal pressure was increased proportionately, until it reached the desired "atmospheric" pressure.

It will be observed that (theoretically) the only stress on the sheeting is a compression across its thickness, also that the sheeting could be made slightly elastic in order to reduce any tensile stresses, resulting from slight maladjustment of the internal air volume. In view of these facts the material can be of limited strength and weight. Other favourable points would be:—

(*a*) No structural limits to size of the "building."
(*b*) Safety from meteor damage.
(*c*) Shielding from Solar heat.
(*d*) No extensive excavations required.

If the sheeting were thought likely to deteriorate it could be "renewed" from time to time by spraying the inner surface with a suitable substance.

J. R. CAMP.

Esher, Surrey.

Lunar Accommodation—II

SIR,

I was very interested to read Mr. P. L. Sowerby's paper and letter (*J.B.I.S.* 13 (I) p. 36 and 62) and would like to comment as follows:—

(1) Airlocks in a subway type of entrance into air inflated domes are an unnecessary complication as the domes themselves would be underground. Airlocks in the sides of domes, as in the R.F.D. gunnery trainer, need not cause serious stresses in the fabric.

(2) If pressure domes must be used immediately, before caves can be found or artificially excavated, then they would be covered with lunar dust to avoid thermal stresses. Otherwise the domes should have no contact with the cave walls and roof in order to avoid uneven stresses and heat loss by conduction.

(3) I would be very interested to hear why pressurized compartments built as units independent of the lunar surface are undesirable on several counts. All considerations seem to favour such a step.

(4) Although Mr. Sowerby points out that pressurized tunnels would not require the usual pit props, etc., I do feel that the general use of the word "uplift" might be misleading. There is no "uplift" when a pressurized dome is sited in a cave without an atmosphere and only in contact with the cave floor. Internal pressure will act in all directions and will try to turn the hemisphere into a sphere. This distortion can be avoided by suitable envelope design without anchoring it to the surface by securing bolts.

(5) What functional requirements can there be for internal walls and divisions in a small dome? The habit of fixing or hanging things on walls does not justify the provision of internal divisions.

(6) While the air-proofing of the walls of caves and tunnels will eventually become desirable, it is most unlikely that this will ever be done with any form of cement, instead liquid sprays depositing an air-tight film of a rubber-like plastic compound would probably be used. Such "paints" would certainly be lighter and less precious than the water required for cement.

(7) Apart from siting domes underground, the next best safety measure against punctures is to place one dome within the other, with the outer one under smaller pressure than the inner one. Self-sealing compounds are of far less importance than methods of detecting small leaks.

O. W. NEUMARK.

London.

A Note on Centrifugal Force

SIR,

Your correspondent, Mr. S. W. Greenwood, regards it as an error to suppose that a centrifugal force acts upon a satellite in a circular orbit about the Earth (*J.B.I.S.*, January, 1954). On the other hand, he allows the existence of such forces in rotating machinery. Their status in connection with the former phenomenon is precisely the same as in relation to the latter. If he denies their existence in the first case, he must do without them in the second also. Since there is a widespread lack of understanding, particularly in engineering circles, of the nature of centrifugal force, I have thought it worth while to contribute the explanation which follows:

A body describing a circle of radius r with steady velocity v is well known to possess an acceleration v^2/r directed towards the centre. If m is its mass, by Newton's Second Law, it must accordingly be acted upon by a force F directed always towards the centre and of magnitude given by the equation

$$F = \frac{mv^2}{r}.$$

In the case of a satellite, F will be the gravitational attraction of the parent body. In the case of a particle of the rim of a flywheel, F will be the resultant of the inwardly directed forces exerted on it by neighbouring particles. The mathematician considers this equation to provide an adequate explanation of the observed phenomenon, as indeed it does. The engineer, on the other hand, is never content with such a simple, crystal-clear, approach. He prefers to complicate matters, and confuse himself into the bargain, by embarking upon a long-winded argument which, when shorn of its jargon and put in logical form,

has been discovered by mathematicians to amount to this: He first looks at the phenomenon from the aspect of an observer moving with the body. If this observer prefers to allow for his motion by introducing a fictitious centrifugal force mv^2/r acting along the outward radius, taking the body to be at rest in all subsequent calculations, he will arrive at the correct equation describing the phenomenon, for a body can only be at rest if the forces acting on it are in equilibrium. But only two forces act on the body concerned, viz.: F along the inwards radius and mv^2/r in the opposite direction. The above equation therefore follows.

The position therefore is this. If we do not disregard the circular motion of a body, Newton's Second Law is adequate. If we prefer to disregard the body's acceleration and assume it to be in equilibrium, a centrifugal force must be introduced to allow for this erroneous hypothesis. Arrival at the correct equation of motion *via* the concept of centrifugal force is now seen to involve most circuitous reasoning. It is a concept which need never be introduced into dynamics, either to describe the motion of satellites or the strains set up in rotating machinery. All types of motion can be analysed by a direct application of Newton's Second Law and are so analysed in reputable mathematical texts. Centrifugal force will not receive a mention in these.

Another "force," of exactly the same nature as centrifugal force is Coriolis force. This force, together with the centrifugal variety, is frequently introduced in ballistics to permit the neglect of the Earth's rotary motion. If the Earth's motion is not neglected, Newton's Second Law again gives the correct equations. Gyrostatic forces are another case in point.

Engineers must undoubtedly be held responsible for the continued popularity of such fictitious forces and for the confusion they engender. By introducing nine or ten principles, each of which can only be applied to one small class of phenomena, instead of remaining satisfied with one all-embracing principle, the engineer appears to believe that he has effected a simplification. Or do engineers consciously attempt to complicate their subject from some ulterior motive? All mathematicians who teach engineering students (as I do myself), would be most interested to learn what advantages accrue from looking at things the crooked way. Perhaps some engineer will enlighten us?

D. F. LAWDEN.

Birmingham.

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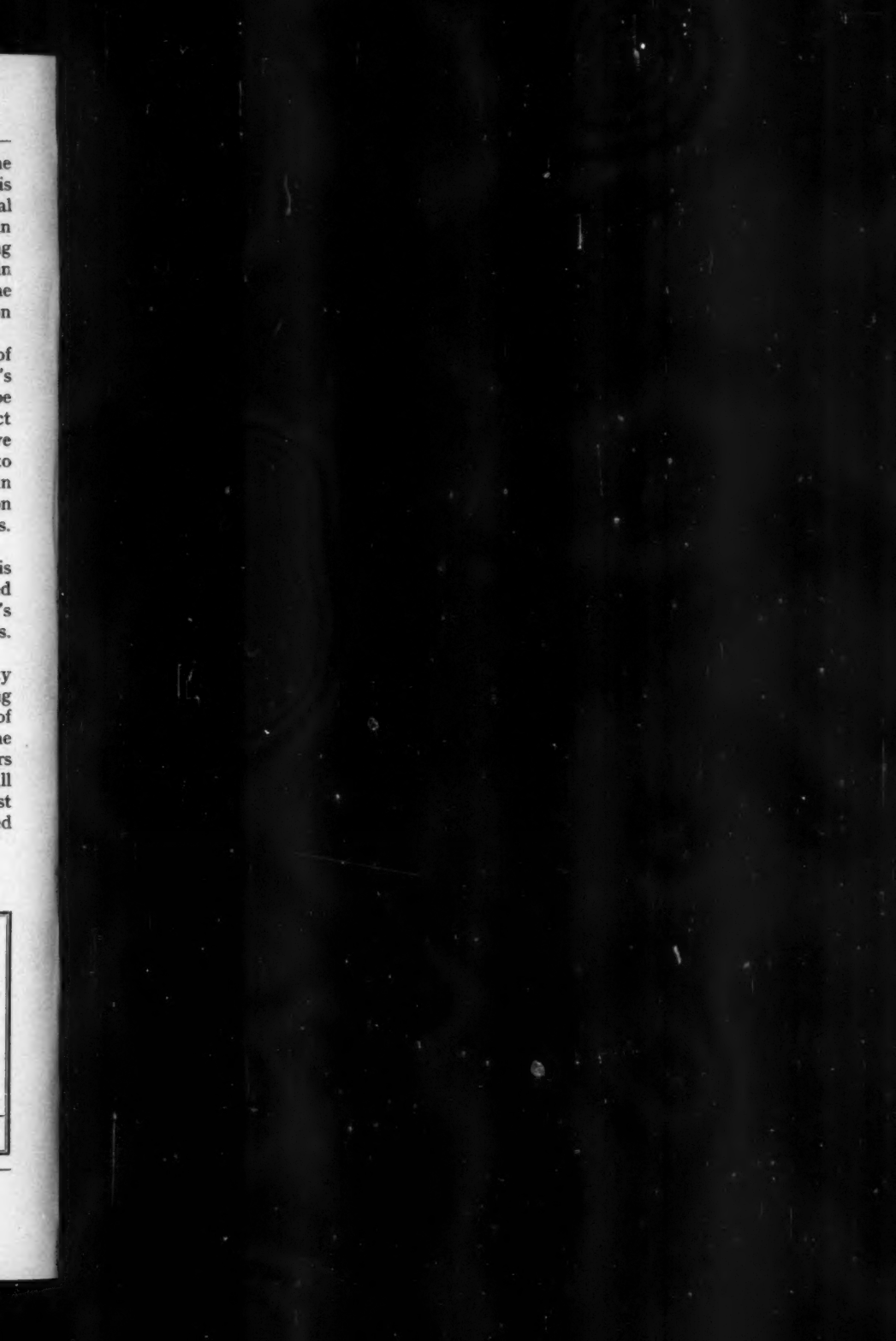
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